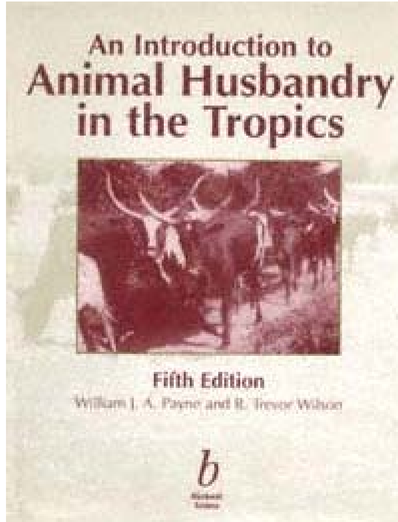
An Introduction to Animal Husbandry in the Tropics

Fifth Edition

William J. A. Payne and R. Trevor Wilson



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Fifth Edition

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CONTENTS

PREFACE:
TO THE FIFTH EDITION

Some forty years after the publication of the first edition of this book in 1959, a number of major changes have been made: four new chapters have been added and the book is once again co-authored. Nevertheless, the original concept of a text that would summarize such knowledge of tropical animal husbandry as is currently available and that will be useful for students, extension and development specialists, administrators and farmers, has been retained.

All chapters have been updated and rewritten. Part I includes two new chapters. A developing world-wide interest in the conservation of genetic resources and the fact that a majority of the world's domestic animal breeds and types are to be found in the tropics make the new chapter entitled 'Conservation of farm animal genetic resources', particularly relevant. In the other new chapter, entitled, 'Sustainable production systems', the need for such systems and the possibility of their development in the tropics are explored.

In Part II the chapter on cattle has been reduced in length, partly by transferring details of working cattle into a new chapter in Part III, entitled 'WorkAnimal Power'. In this the abilities and problems of working animals in tropical agriculture are explored in some detail. The chapter on 'Donkeys' has been expanded to include data on horses and mules. In addition, there is a new chapter entitled 'Microlivestock' in which is detailed the economic utility and husbandry of some locally important but little known and/or studied livestock species.

The many difficulties associated with providing adequate information on a variety of subjects multiply, as knowledge on different aspects of animal husbandry continues to expand. The authors consider that updating and upgrading of the overall text, the comparative approach that has been adopted in most chapters, and the addition of four new chapters will help to alleviate some of these difficulties.

Finally, we wish to express our thanks to the collaborating authors who have written specific chapters and the many other individuals who have advised and assisted in the publication of this edition.

WILLIAM J.A. PAYNE
R. TREVOR WILSON

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PART I
BASIC PRINCIPLES

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1
The Effect of Climate

Tropical Climates

The term 'tropical' is used geographically to designate the area between the Tropics of Cancer and Capricorn. However, climate in this region is not uniform and it is meaningless to talk of a typical tropical climate. It varies with unalterable factors such as latitude, altitude, distribution of land and water, soils and topography, and variable factors such as ocean currents, winds, rainfall and vegetation. The interaction of all these factors result in specific microclimates at specific localities. However, for all their diversity tropical climates exhibit certain common characteristics. Except in the very dry areas and at higher altitudes, daily and seasonal temperature variability is relatively small, being least at the equator. Day length is also fairly constant throughout the year, so that differences in the total hours of sunshine and the total solar radiation depend primarily on the degree of cloud cover.

Climate is a combination of elements that include temperature, humidity, rainfall, air movement, radiative conditions, barometric pressure and ionization. Of these, temperature (Figs 1.1 and 1.2) and rainfall (Fig. 1.3) are the most important. In practice, effective rainfall, that is the amount ultimately available to the vegetation, is a more important index than total rainfall.

Many attempts have been made to classify climates, the best-known being those of Koeppen (1931) and Thornthwaite (1948). Holdridge (1967) proposed a 'Life Zone Ecology' classification combining latitude, altitude, rainfall and mean temperatures that has been particularly useful for agriculturists. A simple classification was proposed by the United States Department of Agriculture (USDA, 1941). In this system climate in the tropics is classified into the following categories: equatorial or super-humid, humid, sub-humid, semi-arid and arid. As shown in Table 1.1 and in Figs 1.4 and 1.5, it has been found that there is a close relationship between these climatic zones and the major vegetation climax types and soils, and a modified form of this simple classification is used in this book.

The general extent of these major climatic divisions in the tropics is shown in Fig. 1.4. This map does not, of course, show local variations in climate within the larger climatic zones.

Equatorial or Super-Humid.

This zone is characterized by constant heat, rainfall and humidity. The mean annual temperature varies around 27°C and total annual rainfall is usually within the range of 20003000 mm. Although in any two- or three-week period there is almost always an excess of precipitation over evaporation, it is not usual for rainfall to be evenly distributed throughout the year. In some areas one season is slightly wetter, while in others there are two wetter seasons.

Equatorial climates are found 57° latitude north and south of the equator and specifically in the Congo basin and part of the Guinea coast of Africa, in the south of the Indian subcontinent, the Malaysian peninsula, Indonesia, New Guinea, the southern Philippines and the Amazon basin. They are also found in isolated

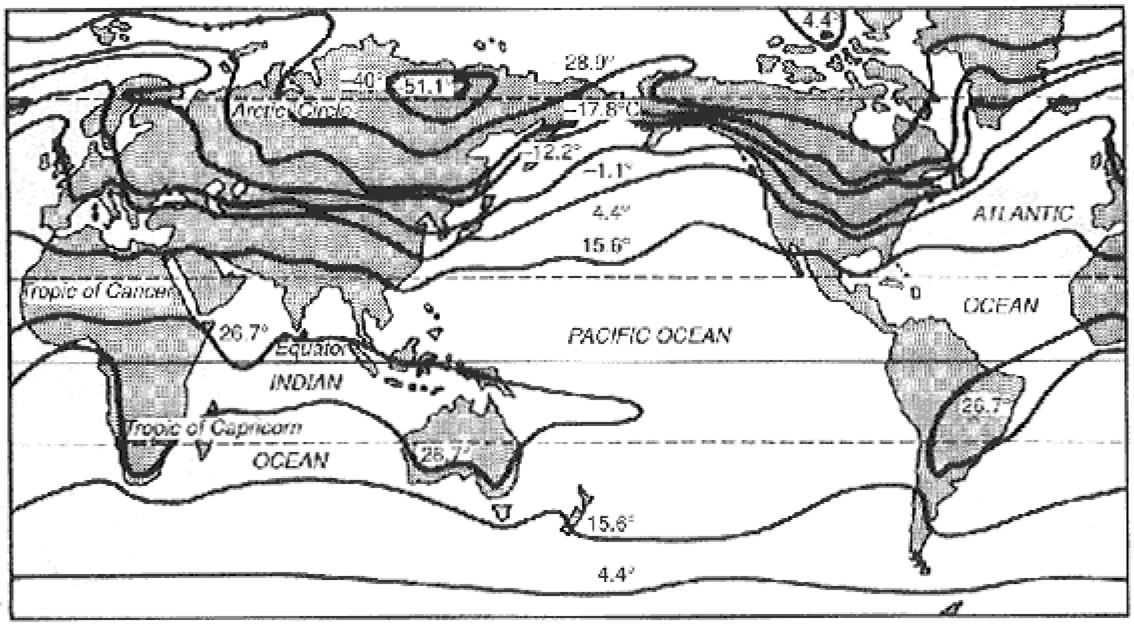

Fig. 1.1
January isotherms of the world in °C (slightly simplified).

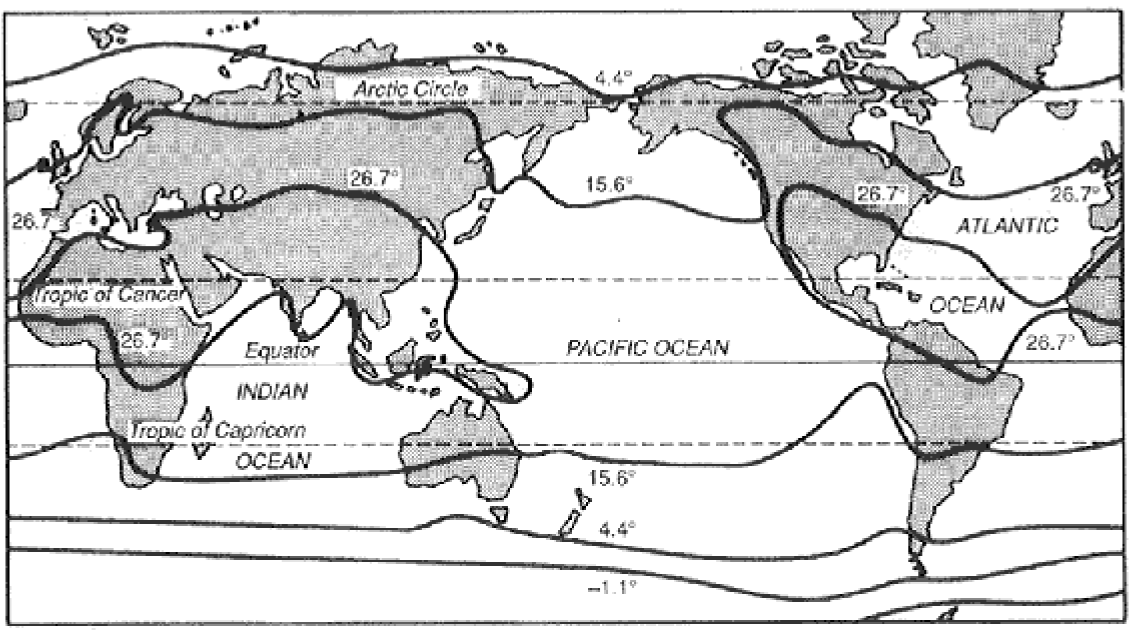

Fig. 1.2
July isotherms of the world in °C (slightly simplified).

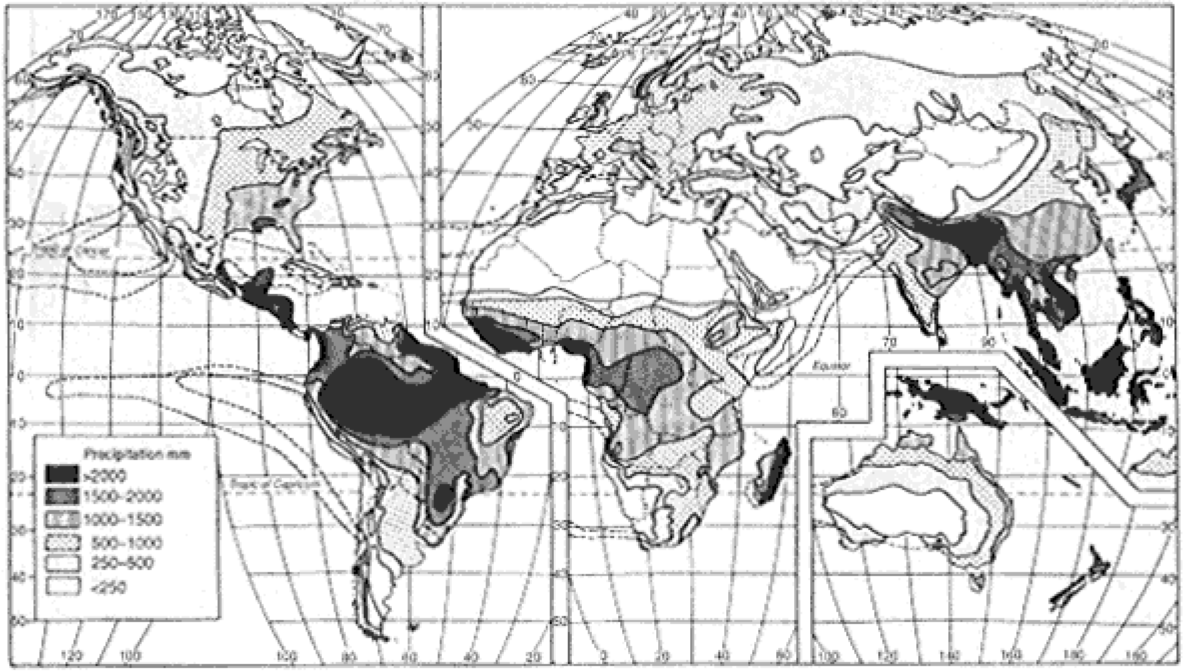

Fig. 1.3
Distribution of precipitation over the earth.

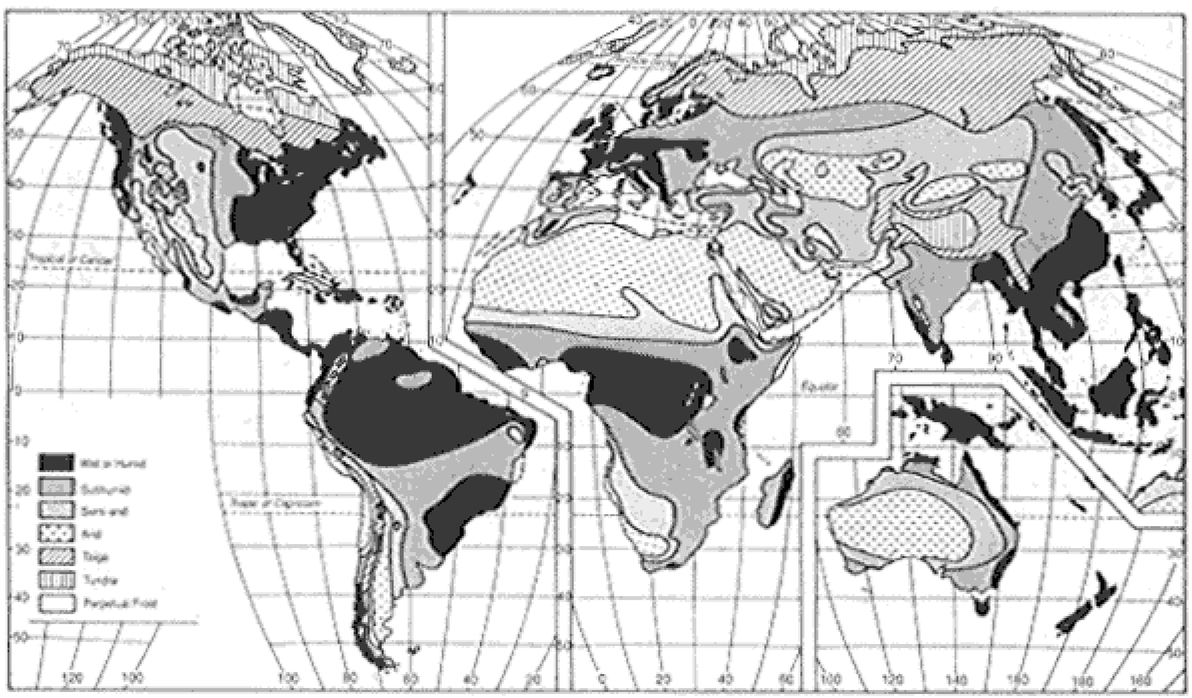

Fig. 1.4
The principal climates of the earth.

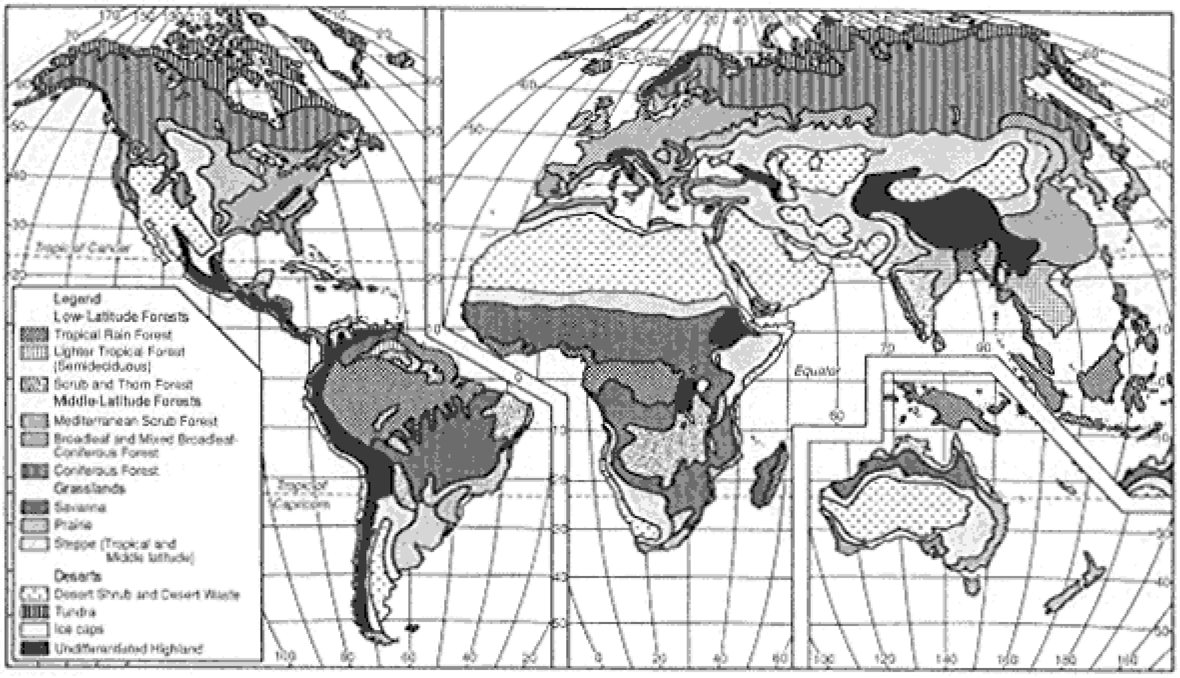

Fig.1.5
World distribution of the principal plant associations.

Table 1.1 Relationship between climate, vegetation type and soil in the tropics.

Climate	Vegetation	Soil
Equatorial or super-humid	Rainforest	Podzols (grey-brown, red and yellow) and laterites
Humid	Forest	
Sub-humid	Grassland	Chernozems and degraded chernozems
Semi-arid	Steppe and thornbush	Chestnut and brown soils
Arid	Ephemeral and desert	Sierozems and desert soils

areas further from the equator, such as the west coast of Colombia and the east coast of Madagascar.

The typical vegetation of this climatic zone is tropical rainforest, characterized by a multiplicity of evergreen tree species, some of them hardwood, covered with epiphytes and intertwined with lianes.

Climatic stress on domestic livestock is considerable in this region. In general, indigenous domestic breeds are not numerous, but the climate favours plant growth so that forage could be plentiful and available all the year round. Internal and external parasites are favoured by the climate and animal products rapidly deteriorate when stored.

The apparent 'high fertility' of tropical rainforest soils is illusionary rather than real as they rapidly deteriorate once the forest has been cleared. Although the potential for animal production is high a great deal of basic and applied research is needed before this region can become capable of supporting a dense and productive animal population.

Humid

The major climatic characteristics of this zone are high though seasonal temperatures, humidity and rainfall. Temperature extremes are wider than in the equatorial region. There are usually three seasons: cool-dry, hot-dry and hot-wet. Climates of this type are found adjacent to the equatorial areas, north and south of the equator, in the monsoonal lands. Somewhat similar climates also occur on the windward side of volcanic oceanic tropical islands.

The natural vegetation of the zone is rainforest, but plant growth is not quite so vigorous as in the equatorial zone; deciduous species are mixed with evergreen species and there are fewer epiphytes and lianes. Climatic stress on domestic livestock is not quite so severe as in the equatorial areas, but forage supplies are more seasonal.

Sub-Humid

In general the sub-humid areas are found north and south of the humid forest areas in the northern and southern hemispheres respectively. They are characterized by a more seasonal climate than in the humid zone. There is usually a relatively short rainy season and a longer dry one, though in some regions there are two rainy seasons. Temperature variations are much wider, with hotter summers due to a high intensity of radiation combined with a longer day.

The natural vegetation of these areas is usually some form of 'savanna', an open grassland association interspersed with trees. Large areas of savanna are found north and south of the equator in Africa, particularly in the east of the continent. There are also large areas in the Indian peninsula, inland in Southeast Asia, in northern Australia and Central and South America and on the leeward side of many oceanic tropical islands. There are many types of savanna with various combinations of high, medium and low trees and tall and short grasses. In the wetter areas savanna imperceptibly merges into dryland forest, such as the *miombo* of Central Africa, while in the drier areas it merges into open short-grass steppes or desert scrub.

This is one of the tropical regions where nomadic livestock husbandry has nourished in the past in Africa and Asia and where European settlers in the Americas and Australia established a ranching industry. It is also a region where, in the past, wild game flourished in vast numbers.

Generally, climatic stress on domestic livestock is less intense than in the more humid areas, but forage production is very seasonal and nutritional stress can be a major problem. This is also the region where epizootic animal diseases are rife, though some internal and external parasites of domestic livestock are easier to control in this region than in the more humid forest areas.

Semi-Arid

This climatic region is characterized by extremely seasonal conditions, with relatively low rainfall and very long dry seasons. Diurnal and seasonal temperature fluctuations are very wide, humidity is low for most of the year and there is a high intensity of solar radiation due to the dry atmosphere and clear skies. Although total rainfall may be within the range of 250500 mm it may be very intense when it falls and very irregular in incidence.

There are large semi-arid areas in Africa, north and south of the savanna regions, in Western Asia and India, and in northern Australia and smaller areas in North, Central and South America. There are also some small, low-lying, oceanic tropical islands that possess a semi-arid climate.

This climatic region is more suited for livestock production than for any other form of agriculture, though productivity is severely curtailed by lack of feed and water, with consequent nutritional stress, as well as by climatic stress. Internal and external parasites can be controlled with relative ease, though control of epizootic disease is more difficult. Often semi-arid areas are more suitable for the management of sheep, goats and camels than they are for cattle, and in the driest areas wild game may be the most suitable and economic exploiters of the environment.

Arid

There are few truly desert areas in the tropics as the great deserts of the world are found in the subtropics or even further from the equator. However, small areas of desert are located within the tropics in the southern Sahara, southwest Arabia and the Pacific coast of northern Chile. Tropical desert climates are characterized by temperature extremes of the order of 052°C and by the fact that there is no seasonal rhythm in rainfall, which is insignificant in total amount.

Deserts may seasonally support very limited numbers of livestock, and in Africa and Western Asia nomadic herdsmen may at certain times follow the rain showers across the deserts, feeding their herds and flocks on the ephemeral plants that spring up as soon as it rains. In parts of Arabia and the Sahara a unique and particularly valuable type of desert vegetation occurs irregularly only after a specific sequence of climatic phenomena. It is known in Arabic as *gizu*.

Montane

This simplified account of tropical climates does not take into account one other major zone, the montane region. A very considerable area of land in the tropics is situated at an altitude varying between 300 and 1500 m and an appreciable area lies above 1500 m. Altitude influences climate in at least four ways. Mean annual temperature decreases by an average 5.6°C for every 1000 m increase in altitude. This decrease is higher on oceanic islands or where there are very steep mountains. Secondly, the higher the altitude the larger the diurnal, though not the seasonal, variation in ambient temperature. Thirdly, rainfall is usually greater at higher altitude and there are more cloudy days. Finally, the higher the altitude the lower the atmospheric pressure, the latter being halved at 5500 m. Three of these influencesnamely a decrease in mean annual temperature, an increase in diurnal temperature variation and a higher rainfallare likely to assist in the improvement of livestock productivity.

It is difficult to generalize, but in equatorial and humid tropical rainforest areas the species composition of the forest alters with increasing altitude and gradually merges into other vegetation complexes. In the drier tropical areas the open plains vegetation merges into cool, humid forest as the annual rainfall increases with increasing altitude. Above 4000 m there is usually an alpine-type vegetation even on the equator.

To date little has been done to exploit these montane areas for livestock production, though they offer opportunity for the development of dairy industries based on temperate-type dairy cattle, temperate-type beef breeding operations producing bulls that could provide semen for use in crossbreeding schemes at lower altitudes, large-scale hill sheep production, and in South America major increases in the production of meat and wool from the domesticated and wild llamoids such as the alpaca, the llama and the vicuña.

The Effect of Climate on Livestock

Livestock production in all tropical countries is affected by the climate in two ways. First, by a direct influence on the animals and second by indirect effects on the animals' environment.

Climatic Requirements for Optimal Production

Major climatic variables directly affecting domestic livestock are temperature, humidity, air movement and radiative conditions. In addition, the duration of light (the photoperiod) is of importance for some species as it affects various aspects of reproduction and other biological functions.

Combinations of these climatic variables create climates in which maximum productivity can be achieved by specific types of livestock. The climates may vary on account of interactions between the climatic variables and diurnal, daily and seasonal changes. The combinations will certainly vary according to whether optimal productivity is sought in growth, milk production, or reproductive processes. Additional variables in this scenario are the genetic adaptabilities of the species, breed or individual animal; adaptability being based on physiological/biochemical/neurochemical/behavioural characteristics.

Thus the situation is very complex, with different climatic requirements for different livestock and for different aspects of livestock production. For example, temperate-type Holstein cattle have a thermal comfort zone for milk production within the range -5 to 20°C, with optimal production at around 10°C and with a critical temperature range, after which milk production declines steeply, of 2127°C. However, the critical temperature, after which milk production declines, is somewhat higher in some other temperate-type breeds, such as the Jersey and the Brown Swiss and higher still in tropical breeds.

If growth, rather than milk production, is the factor studied the comfort zone is different and varies with age. Most very young livestock require higher ambient temperatures immediately after birth than they do at later stages of growth. Specific climatic requirements for the different species are considered later in 'Part II: Husbandry'.

There is some confusion in terminology with regard to this subject as the thermal comfort zone is not the zone of minimal heat production by the animal, but the ambient temperature range within which the metabolic rate of the animal is independent of environmental temperature.

The Direct Effect of Climate on the Animal

Experimental evidence on the direct effect of climate on domestic livestock has been obtained from two sources: direct observations in the field and observations on livestock kept in controlled-temperature laboratories or psychrometric chambers. The disadvantage of direct observations is that it is difficult to set up adequately controlled field experiments, while the disadvantage of using a psychrometric chamber is that only a small number of the larger domestic livestock can be studied at any one time while it is known that there are profound differences between species (Findlay, 1954), breeds or types within a species (Worstell & Brody, 1953) and individuals within a breed (Payne & Hancock, 1957) in their ability to withstand the direct effects of climate.

Heat Balance.

All domestic livestock are homeotherms. That is, they attempt to maintain their body temperatures within a range most suitable for optimal biological activity. The normal range in mammals is 3739°C while in birds it is 4044°C though there are some exceptions. Typical deep body temperatures of some domestic livestock are shown in Table 1.2.

It must be emphasized that the data in Table 1.2 comprise average body temperatures for livestock in thermal comfort zones. Under stress conditions body temperatures can vary; a

Table 1.2 Typical deep body temperatures of domestic livestock.

Type of livestock	Deep body temperature (°C)
Mammals	
Asses	36.038.0
Buffaloes	38.038.5
Camels	36.038.0
Cattle	38.039.3
Goats	38.740.7
Horses	37.238.2

Pigs	38.939.4
Rabbits	38.640.1
Sheep	38.339.9
Birds	
Ducks	42.1
Fowls (chickens)	40.643.0
Geese	41.3
Turkeys	41.2

characteristic in camels and some other ruminant livestock that assists adaptation to high daytime ambient temperatures. This phenomenon is discussed in Chapter 11.

In order to maintain their body temperature while subject to a wide range of environmental conditions, domestic livestock must preserve a thermal balance between their heat production or gain from the environment and their heat loss to the environment. This thermal balance can be expressed by the equation:

$$M - E \pm F \pm Cd \pm Cv \pm R = O$$

or

$$M = E \pm F \pm Cd \pm Cv \pm R$$

where *M* is the metabolic heat production, *E* is the heat loss from skin and respiratory passages by evaporation, *F* is the heat lost or gained bringing ingested food and/or water to body temperature, *Cd* is the heat lost or gained by direct contacts between the body and surrounding surfaces, *Cv* is the heat lost or gained by convection due to contact between the air and skin and/or linings of the respiratory passages, and *R* is the heat lost or gained by radiation. Some of the factors influencing the equation are also shown diagrammatically in Fig. 1.6.

Metabolic heat production (*M*) depends on:

(1) Basal heat production for maintaining essential body processes such as deep body temperature, cardiorespiratory activities and muscle tone.

(2) Digestive heat production that varies with the type of digestive system that the animal possesses and on the quantity and quality of the food that it ingests.

(3) Muscular heat production that varies according to how much the animal moves about in grazing and other activities.

(4) Increased metabolism due to productive processes such as growth, milk production and reproduction.

In general, the means by which domestic livestock can vary their heat production are limited in comparison with the methods by which they can dispose of heat. They can reduce productive processes and muscular heat production and, to a

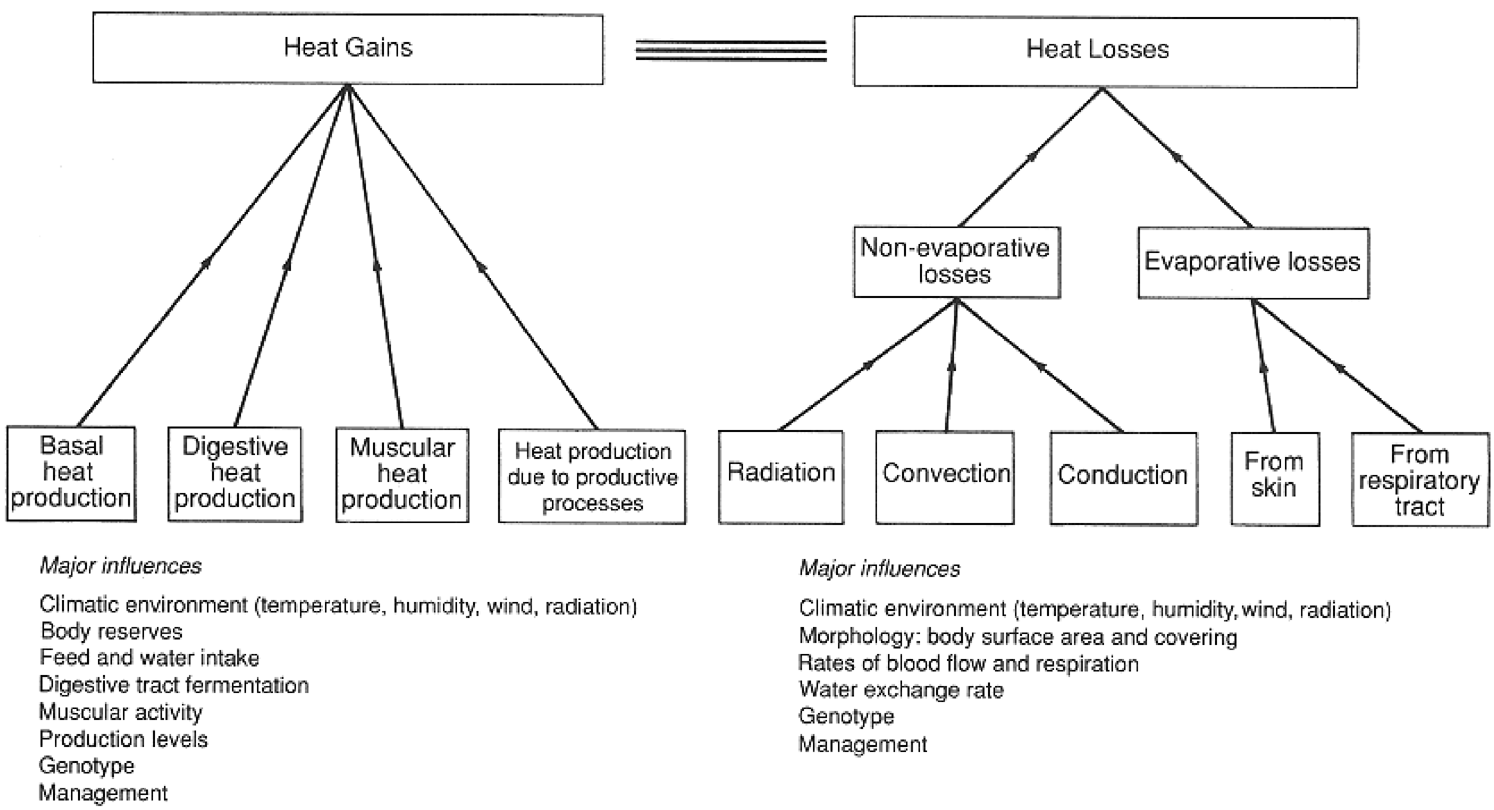

Fig. 1.6
Diagrammatic illustration of the major factors affecting the thermal balance.

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more limited extent, digestive heat production, but they cannot easily reduce basal heat production as minimal body processes must be maintained.

Of the methods of heat loss available to domestic livestock, evaporative loss is potentially the most important under normal circumstances. This includes losses from the skin, mainly by sweating, and respiratory losses by panting. The relative importance of these methods of heat loss varies between species and breeds. Skin loses water by diffusion through the epidermis (insensible perspiration) and active secretion of sweat. The heat loss achieved depends upon the ambient temperature, absolute humidity and degree of movement of the air surrounding the animal, the volume of available moisture and the area of the evaporating surface. The volume of available moisture includes the insensible perspiration and sweat from the animal unless it is sprinkled with water or has access to some form of water bath or wallow. The quantity of sweat produced depends on the number and type of sweat glands per unit area of skin and this varies between species as does the method by which sweat glands release sweat.

Of the domestic mammals, horses possess well-developed sweat glands in contrast to rabbits in which sweat glands are usually absent. Others, such as cattle, buffaloes, sheep, goats, and pigs possess sweat glands but are in general poor sweaters. In cattle, however, *Bos indicus* breeds usually possess a higher total volume of sweat glands than do *Bos taurus* breeds.

Poultry possess no sweat glands, as birds could not possibly evolve sweating as a cooling mechanism and still fly. If they had to evaporate water from their skin the air between the feathers would have to be constantly renewed and this would cause turbulence and drag in flight. They accomplish some evaporative cooling by panting and the extensive air-sac system connected with their lungs may also have an important heat-regulatory function.

Respiratory water loss depends on the ambient air temperature, the difference in water vapour pressure between the inhaled air and the moist mucosa of the respiratory tract, the respiration rate or rate of passage of air through the lungs and the area of moist mucosa. It differs between species. Some animals pant through the nose, some through the mouth, others augment evaporation from the lungs by evaporation from a protruding tongue.

It is generally considered that panting is auxiliary to sweatinga second line of defence for animals such as cattle and sheep that makes up for their relative inability to sweat by possessing relatively high rates of panting.

The heat gained or lost by the animal bringing the food and/or water ingested to body temperature can have a considerable effect on total heat production and loss. Any water consumed in excess of metabolic needs, at a temperature lower than body temperature, and then excreted at body temperature as urine or in the faeces, assists in reducing the heat load on the animal. Lowering the temperature of ingested water is known to have a more marked effect on the heat load than increasing the volume ingested. This effect has practical significance and as Baker *et al*. (1987) have stated, under conditions of relatively high humidity, chilled drinking water can assist lactating dairy cows to maintain production through periods of high environmental temperatures.

The ability of most livestock to lose heat through conduction is very limited. Convection heat loss is of course increased when cool breezes blow on the animal, and increased air movement may also increase evaporative heat loss. Consequently, livestock accommodation in the tropics should always be built in such a way as to encourage maximal air movement on and around the animals. There has been an increasing interest in using economic cooling methods that combine heat loss from evaporation and increased air movement, particularly for improving the production of high-producing dairy cattle during periods of high ambient temperature. These include air conditioning, fogging and the installation of water sprinklers and/or forced air fans in holding pens, milk parlour exits and shaded yards. Some of these methods and the results obtained are detailed in Chapter 7.

Solar radiation may not only increase the heat load on the animal but also directly affect the skin, causing skin cancers and other photosensitive disorders. This means that the colour and thickness of the skin are of some importance as adaptive mechanisms. A pigmented skin is considered more desirable than an unpigmented skin everywhere in the tropics and the majority of tropical-type breeds possess pigmented skins, while many temperate-type breeds possess unpigmented skins.

Individuals of the Hereford breed of cattle often suffer from an eye condition known as epithelioma because they possess unpigmented eyelids, and white-skinned breeds of pigs such as the Large White are particularly susceptible to sunburn.

The amount of solar radiation absorbed by the coat of the animal is partly determined by its colour. Approximately half of the energy in the solar spectrum is in the visible portion and half is in the invisible infra-red portion. The proportion of the visible portion that will be absorbed by an animal can be approximately estimated by the colour of the coat, as a white surface may absorb only 20% while a black surface may absorb 100% of the visible radiation. Energy from the invisible infra-red part of the solar spectrum is completely absorbed whatever the colour of the coat. Colour is not the only factor that affects the influence of solar radiation on the heat load of the animallength, density and condition of the hair may also have some effect. Smooth-coated animals with short hair appear to be more heat tolerant, so that Bonsma (1949) suggested that the degree of 'felting' of samples of cattle hair could be used as a measure of heat tolerance. Yeates (1965) reviewed the available experimental data and these indicated that a short, lightcoloured coat with a smooth and glossy texture is best for minimizing the adverse effects of solar radiation on growth and other productive processes. Posture also has some effect on minimizing the heat load due to solar radiation, as animals that are standing do not receive as much solar radiation per unit body area as do those that are lying down.

The length of daylight not only affects the degree of solar radiation to which domestic animals are exposed, but also metabolic rhythms, reproduction and hair and wool growth. As length of daylight in the tropics is not very variable it is considered unlikely to have a major effect on the reproductive characteristics of domestic mammals and birds. There are, however, some effects on some species (Thimonier & Chemineau, 1988), including the consideration that the lack of variation can delay the seasonal shedding of woolly coats by some temperate-type cattle imported into the tropics.

Grazing Behaviour

The effect of climate on livestock is reflected in their grazing behaviour. This has been studied in cattle more often than in any other species, the subject having been reviewed by Payne (1969).

The length of daytime grazing of cattle apparently varies according to the degree of climatic stress, the breed and type of cattle utilized, and the quantity and quality of the pasture available. When high-grade *Bos taurus*-type cattle are grazed in a humid tropical climate the length of daylight grazing is radically curtailed and confined almost entirely to early morning and late afternoon periods (Fig. 1.7), and the length of the night grazing period fluctuates according to the degree of climatic stress. Even crossbred *Bos taurus* × *Bos indicus* cattle graze for such a short period in the middle of the day that yarding

Fig. 1.7
Crossbred cattle seeking shade under an oil palm in Brunei.

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them for a 4-hour period at this time, without access to feed, does not reduce total dry matter intake.

In many parts of the tropics, indigenous cattle are removed from the grazings and confined during the night. It is usually stated that this is done to protect them from predators, both human and animal. However, the majority of observers suggest that whenever possible *Bos indicus* and other indigenous cattle should be allowed to graze at night, particularly when the quantity and quality of the feed available is suboptimal. If the quantity of feed available is limited total grazing time increases, as it does when the quality is poor, and the animal then becomes more selective in grazing. Part of this extra grazing must take place at night if climatic stress is excessive during the middle of the day. Joblin (1960), working at Serere in Uganda, where seasonal fluctuations in the quantity and quality of feed are considerable, concluded that the availability of night grazing is critical for *B. indicus* cattle during periods of marginal forage shortage; and that while under the best conditions the daylight period is sufficiently long for the cattle to obtain their needs, under very dry conditions no amount of grazing time will allow for adequate intake. Restriction of night grazing led, in the Serere environment, to a significant decline of 30% in liveweight gain. These experimental findings have since been verified by other workers in other tropical countries.

Relatively few observations have been made of the grazing behaviour of cattle managed under nomadic or semi-nomadic conditions in the semi-arid tropics. During the dry season the decreasing water content of the available forage increases the animal's demand for water at a time when surface water resources are dwindling, and the animal has to walk further and further to obtain adequate feed and water. Additional walking raises feed and water demand as increased muscular activity requires additional feed and generates extra heat that has to be dissipated, further depleting the animal's water resources. At the same time, the nutrient content of the available feed decreases as the dry season advances, the decreasing supplies of free water may become highly mineralized, and ambient temperatures may rise with a consequent further increase in the animal's water requirements. All these factors combine to subject nomadic or partially nomadic livestock in the semi-arid tropics to very considerable physiological stress that may substantially reduce productivity.

Adeyemo *et al*. (1979), observing the behaviour of *Bos taurus* (German Brown and Holstein-Friesian) and *Bos indicus* (White Fulani) cattle in the equatorial climate of southern Nigeria, noted that the Fulani were the best adapted and did not normally seek shade whilst the Holstein-Friesian were least adapted. All the cattle were most comfortable during the wettest periods of the year.

Intake and Utilization of Feed and Water

Feed Intake

As would be expected from the effect of temperature on grazing behaviour, the available climatic chamber data suggest that high ambient temperatures depress the feed intake of domestic livestock, but that in the case of cattle the feed intake of *Bos taurus* is depressed at lower ambient temperatures than is that of *Bos indicus* breeds. The effect of very high temperatures is very pronounced, food consumption and rumination practically ceasing in *B. taurus*-type cattle as ambient temperatures rise above 40°C. Some other livestock species particularly camels, do not reduce their feed intake until ambient temperatures are higher than those that radically reduce the intake of cattle.

Increasing humidity at ambient temperatures above 23.9°C also depresses the feed intake of all cattle, while increasing radiation stress has the same effect on *Bos taurus* but not on *B. indicus*-type cattle.

Field data should reflect more accurately than climatic chamber data the overall effect of the climatic environment on the feed intake of livestock. Unfortunately, the available data are limited. Hancock & Payne (1955) and Payne & Hancock (1957) compared the performance of sets of *Bos taurus* identical twins fed hay and concentrates, one twin of each set being raised in a tropical climate and the other in a temperate climate. They showed that hay intake was significantly lower in a tropical climate although overall total digestible nutrient (TDN) intake was approximately the same in both environments.

Many other experiments have shown that livestock limit food consumption when they are heat stressed. In cattle, one explanation for this behaviour may be that when fed a high forage diet they produce a high ratio of acetic to proprionic acid in their rumen and that this increases the heat increment and thus heat stress (Tyrell *et al*., 1979). If, however, cattle drastically reduce their forage consumption they reduce the acetic to proprionic acid ratio in their rumen with a consequent decrease in the heat increment.

The interactions between feed intake and heat stress have been reviewed by Yousef (1985) and further information is provided in the chapters on specific types of livestock.

Water Intake

The direct effect of climate on the water intake of livestock is very complex as water is required by the animal for at least two different purposes: first as an essential nutrient and component of the body, and second to assist the animal lose heat by conductive or evaporative cooling. The subject is discussed in some detail by King (1983).

Although, in general, the water intake of livestock increases with increasing ambient temperature the relationship is not simple. For example, in *Bos taurus*-type milking cows water intake increases with rising ambient temperature up to 29.4°C, but above this temperature it declines. This decline has been attributed to a decline in feed intake and productivity and to a rise in body temperature (Winchester, 1964).

Ambient temperature has a differential effect on the water intake of different types of livestock and on different breeds within one type. For example, the water intake of sheep on a metabolic weight basis appears to be no more than 40% that of cattle managed at the same ambient temperatures and acclimatized animals require less water than unacclimatized ones. There are wild desert-living mammals that require little if any free water, their needs being satisfied by water in the forage that they consume.

Humidity also affects water intake, and at ambient temperatures above 24°C increasing humidity decreases water consumption but increases the frequency of drinking by cattle. The effect of increased radiation intensity on cattle is to increase water consumption. Presumably this is due to the animal utilizing an increasing quantity of water for evaporative cooling purposes when subject to radiation stress.

Efficiency of Utilization

The experimental evidence available suggests that under controlled conditions increasing ambient temperature decreases the efficiency of feed utilization, although under field conditions any differences may be insignificant.

Loss of Nutrients by Sweating and Drooling

Sweating is not of the same importance in all livestock, though it can be important in cattle. In the latter, sweating behaviour differs between breeds as ambient temperature rises. Generally, the loss of nutrients and particularly minerals through sweating and drooling is not of practical significance, but it may be in high-producing dairy cattle (Sanchez *et al*., 1994).

Growth

If climatic stress depresses appetite, reducing feed intake and grazing time, then it is likely to affect productivity as measured by growth and milk production.

Although many generalized statements have been made with regard to the adverse effects of a tropical climate on growth there is remarkably little objective field experimental evidence available. In the FijiNew Zealand twin experiment mentioned in a previous section, the growth of the twins was studied from 71/2 months of age until the end of their first lactation (Hancock &

Payne, 1955). The only appreciable differences in growth rates were when air temperatures in Fiji were at their highest: at calving the heifers reared in the temperate climate were only 9.6% heavier than the heifers reared in the tropics, and by the end of the first lactation this difference was substantially reduced. The check in growth rate was reasonably uniform, in so far as all body measurements except belly girth were adversely affected. The belly girth of the twin reared in the tropics was greater and this was attributed to the fact that they had a much greater water intake. Management conditions were good in this experiment, and the results suggest that an oceanic tropical climate does not appreciably affect the growth rate of temperate-type cattle if management and feeding conditions are of a high standard.

There is very little experimental evidence on the effect of the different climatic factors on the growth rate of *Bos indicus*-type cattle. The birth weights of most *B. indicus* calves are low and they often grow rather slowly, but what part, if any, of this poor growth can be attributed to the direct effect of the climate is unknown.

Information on the effect of climate on the growth of sheep and goats is also scanty. Temperate-type sheep in the Australian tropics exposed to high ambient temperatures often have a low lambing percentage and give birth to small, weak lambs that have a high postnatal mortality. It is also reported from Australia that autumn-born lambs which have been carried through the hot summer are usually smaller at birth than spring-born lambs, but it is very difficult to disentangle the direct from the indirect effects of the climate. The young lamb or kid, like the young calf, is certainly less well adapted to high ambient temperatures than adult animals. The effect of climate on sheep is further discussed in Chapter 9.

At birth the piglet does not appear to possess a very efficient temperature-regulating mechanism and is incapable of protecting itself against either excessive heat or cold. During the first 2 days of life the ambient air temperature for piglets should exceed 32°C and then be gradually lowered as they grow older. It is now normal practice in temperate countries to use infra-red lamps to warm the piglets immediately after birth, so that they do not get chilled. As in the tropics the mean annual temperature varies around 27°C and in the daytime temperatures are often of the order of 32°C or higher, the problem is not so acute, but it has been found that even in a tropical climate piglet mortality due to overlying may be reduced by the use of an additional heat source during the first few days of life. As the pig ages and grows the optimal air temperature for maximum liveweight gain and efficiency of food conversion falls and pigs weighing 3265 kg are probably being reared under almost optimal ambient temperature conditions. At higher liveweights normal tropical temperatures are too high for maximum productivity.

Chicks are more tolerant of high ambient temperatures than are adult birds, but when the air temperature is above 35°C there is a danger of day-old chicks overheating in chick boxes when they are transported from the hatcheries. High ambient temperatures probably reduce the rate of growth of poultry though there are considerable differences in the reactions of different breeds, light breeds withstanding heat better than heavy breeds.

Milk Production

Experimental evidence on the effect of climate on milk, butterfat and solids-not-fat production in cattle has been reviewed by Johnson (1985). Most of the available experimental evidence indicates that milk, butterfat and solids-not-fat production are depressed by high ambient temperature, but as in growth studies it is difficult to disentangle the direct and indirect effects of climate. In the FijiNew Zealand identical twin experiment, where it was possible to assess the effect of the climatic environment independently of management and feeding (Payne & Hancock, 1957), climate had a marked effect on milk and butterfat but not on solids-not-fat production. The average milk production of the twins in the temperate climate was 44% higher than that of their co-twins in the tropics and their butterfat production was 56% larger. There were, however, profound differences in the reaction of individual twins at the same centre to the climatic environment.

Experimental work with dairy cattle in psychometric chambers has provided more detailed information as to the effect of individual climatic factors on milk and milk solids production.

The optimal temperature for milk production in temperate-type cattle breeds appears to be 10°C, while the critical temperature after which milk production steeply declines is 2127°C in Jersey and Holstein breeds, 2932°C in Brown Swiss and somewhat higher in the case of tropical-type cattle. The butterfat content of the milk of temperate cows declines slowly until the ambient temperature reaches 29°C and then rises. This is presumably due to the fact that above 29°C the decline in milk production is more rapid than the decline in the percentage of butterfat in the milk.

High ambient temperatures also affect other constituents of the milk of temperate-type milking cattle. Rodriques *et al*. (1985), studying 15 years of records at the University of Florida, noted an increase in the chloride content of milk when ambient temperatures rose above 21°C and a decline in fat and protein content. These results confirm earlier chamber experimental work that suggested that there was a rise in the chloride content and a fall in the lactose and total nitrogen content of cows' milk when ambient temperatures rose above 27°C.

There is limited information on the effect of climate on the composition of the milk of other domestic livestock.

Reproduction.

The major climatic factors affecting reproduction are ambient temperature, humidity and photoperiod.

The known effects of climatic stress on the reproductive behaviour of cattle are depicted in Fig. 1.8 and the more important are discussed by Chemineau (1993). The practical implications of these effects are discussed in detail in Chapter 7.

High environmental temperatures appear to have a marked effect on the reproductive behaviour of sheep (Moule, 1970). In the ewe there is evidence from field observations that both embryonic death and fetal dwarfing occur in a hot environment, and from climatic chamber work that continuous exposure to air temperatures that raise rectal temperatures by 1.11.7°C will eventually kill all embryos. Air temperatures above 33°C affect both ova and semen in the

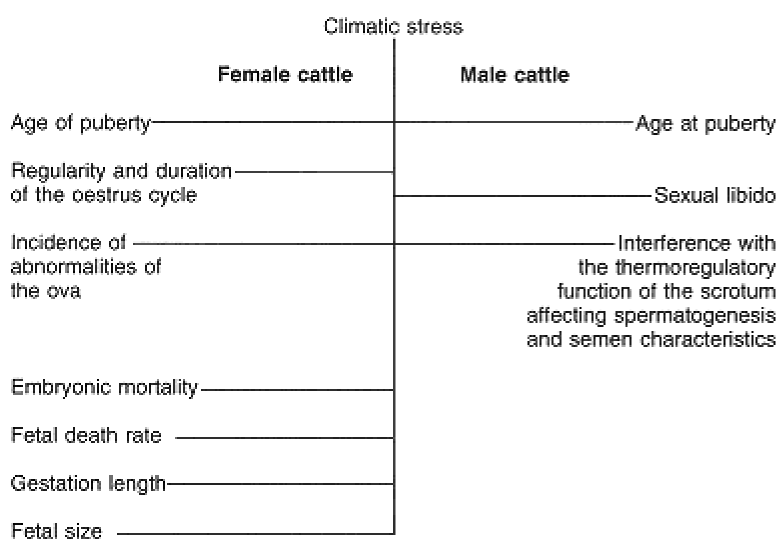

Fig. 1.8
Diagrammatic representation of the known effects of climatic stress on the reproductive behaviour of cattle.

female tract of ewes, presumably by raising body temperature. In rams exposed to high air temperatures in the field, degenerative changes in survival characteristics are reported, though there appears to be considerable variation in the testicular temperature of individual Merino rams exposed to high ambient temperatures (Moule, 1970). Readers may obtain more information on this subject from a review of the subject by Thwaites (1985).

Male sheep and goats imported into the tropics from the temperate zone appear to be less fecund or even sterile for up to 1 year after importation (Moule, 1970). This is presumed to be a photoperiodic effect.

High ambient temperatures also appear to affect embryo survival in sows and may have some effect on oestrus (Curtis, 1985).

Egg production in poultry is highest when air temperatures are within the thermoneutral range. Constant high ambient temperatures affect the rate of laying of eggs and the total number laid, and there is a diminution in egg weight and shell thickness. Water deprivation enhances these inhibiting effects. The fertility and hatchability of eggs is also decreased by high ambient temperatures. Variation in the intensity of light does not appear to affect egg production significantly.

The Indirect Effect of Climate on the Animal

The major indirect effect of climate on livestock in the tropics is on the quantity and quality of the feed available for them. Experimental data on this subject have been reviewed by Payne (1969). Other indirect effects of importance are on the incidence of disease and parasites and on the storage and handling of animal products.

Feed and Water Supply

The most important climatic factors that limit plant growth, and hence the quantity of the feed available, are ambient temperature, effective rainfall, length of daylight and the intensity of solar radiation. The quality of feed depends mainly on effective rainfall and on the intensity of solar radiation. The very real differences in climate that exist between the humid and the arid and semi-arid tropical regions thus present two broadly distinct livestock nutritional problems, although there are many exceptions and the distinctions become blurred in the intermediate climatic zones.

Equatorial and Humid Tropics

In general, forage growth is continuous and very rapid though still seasonal, and under 'high' farming conditions very heavy annual yields may be obtained. There are numerous papers detailing yields of humid tropical forage plants and much information has been obtained during the last several decades on their composition and digestibility.

Effect on Feed and Water Intake

It is logical to expect that forage grown under conditions of abundant rainfall and high humidity should possess a high water content and most studies show that this is so. Whether this high water content of humid tropical forage inhibits ruminant animals from obtaining a sufficiently high dry matter intake is a controversial question, but the balance of evidence suggests that the high water content of, or the free water on, humid forage may affect the total quantity of feed consumed (Payne, 1969).

Effect on the Nutrient Content of the Forage

The experimental evidence is conflicting but, in general, it suggests that forage plants are more nutritious in the wet than in the dry season. Most, but not all, reports conclude that there is a positive correlation between rainfall and the crude protein (CP), silica-free ash and nitrogen-free-extract content of the forage, and an inverse relationship between the rainfall and the crude fibre (CF) content. It is possible that conflicting reports may be due to an attempt to compare the behaviour of different forage species in what are really different climatic environments, and to the

fact that although cutting intervals may be the same, the species may be at different stages of growth at different periods within the same season. Field observations suggest that, after the first 'flush' at the beginning of the rainy season, growth slows down owing to continuous cloudy weather, but that it may increase very rapidly during sunny intervals.

It was generally assumed that the nutritive value of humid tropical forage was severely limited by its reported low CP content, but more recent work suggests that the digestible crude protein (DCP) content of the herbage for which data are available is more variable throughout the year than the energy content and that the latter is likely to limit production for more months of the year than the level of DCP.

The CF content of humid tropical forage is not only inversely related to the amount of rainfall but appears to be consistently higher than that of temperate forage at the same stage of growth. This is an additional disadvantage to animals that are already under heat stress.

Semi-Arid and Arid Tropics

It is characteristic of semi-arid and arid regions that the total rainfall is low, varying widely in amount from year to year and is strongly seasonal and/or erratic in incidence. Thus, it is usual for the rainy season flush of highly nutritious forage to be followed by a long dry period, when growth ceases completely and the forage dries up. If a drought intervenes, the dry season may not be followed by a normal rainy season, but by a few scattered showers and an even longer dry period. Under these circumstances ruminant livestock have to graze for the major part of the year on what is essentially standing hay, and in drought periods they may have to exist on this type of feed for a very long period, at a time when surface-water resources are diminishing. In the truly arid areas forage growth is ephemeral, occurring only after the infrequent rains.

Thus, the major problems of the nutrition of livestock in the semi-arid and arid tropics are the intensely seasonal nature of the forage resources and the possibility of low nutrient intake and water deprivation during the dry season.

Effect on Feed Intake

The dry matter (DM) content of forage in the arid and semi-arid tropics is high throughout most of the year and grazing animals have no difficulty in obtaining an adequate DM intake if ample supplies of forage are available. Thus, the crucial factor in the feeding of livestock in these areas is that of keeping the stocking rate within the 'carrying capacity' of the dry season grazings.

Effect on Water Intake

All domestic livestock require access to free water at some time, but the needs of different types of livestock vary. Cattle require access to free water at all times, though the water demands of different types of cattle vary and *Bos indicus* breeds apparently require less free water than do *B. taurus* breeds when managed in the same environment. The comparative water demands of sheep, goats and camels are not as high as those of cattle. When adequate free water is available the water intake of all types of cattle rises during the dry season but cattle can be acclimatized to a certain degree of water deprivation.

Water Deprivation.

This affects water and feed intake, metabolism and productivity. Cattle restrict their DM intake when they are water-deprived, but *Bos indicus* breeds do not reduce their DM intake to the same extent as do *B. taurus* breeds (Payne, 1965). The higher the ambient temperature the more depressing the effect of the same level of water deprivation on DM intake. If at the same time cattle are managed in such a way as to restrict their grazing timethis being normal managerial practice in many tropical countriesfeed intake may be decreased still further. While the animal is water-deprived, the nutritive

content of available feed may decrease, as is normal in the semi-arid tropics with the advancing dry season, and this may lead to a further decrease in voluntary DM intake (Payne, 1965). The cumulative effect of all these factors may mean that the nutritive intake of cattle in this environment is very inadequate.

As rumen fluid provides the most suitable source of water to offset water losses during the initial stages of dehydration it could be expected that water deprivation would affect rumen function. It is thought that this happens, and there is experimental evidence that water deprivation in cattle increases the digestibility of the feed ingested and in particular the digestibility of the crude fibre component of the feed. Of course, this improvement in digestibility need not be the direct result of water deprivation but could be due to an indirect effect, such as reduced feed intake.

Subjective field observations suggest that some cattle thrive better than could be expected in the very severe nutritional stress environment experienced towards the end of the dry season in semi-arid tropical areas. One obvious reason for the better-than-expected performance is the undoubted ability of most ruminant animals to select those parts of the forage plant that are usually of the highest nutritive value. However, towards the end of the dry season, there is often no leaf material left on the grazing or browse species and the animal is forced to ingest feed of extremely low nutritive value. It is therefore likely that there are other factors that assist the survival of cattle under extreme nutritional stress conditions. Livingston *et al*. (1962) investigated the metabolism of *Bos taurus* and *B. indicus* cattle under simulated nutritional stress conditions and found that they were able to reduce nitrogen output and particularly urea excretion in their urine to a low level. Payne (1965) reported that when the CP intake of *B. taurus* and *B. indicus* cattle was so low that they were in negative nitrogen balance, severe water deprivation improved their nitrogen balance. Rogerson (1963) investigated the effect of declining nutrient intake and water deprivation on energy metabolism in *B. taurus* and *B. indicus* and concluded that cattle on a low-protein roughage diet might also be better able to maintain themselves in positive energy balance if they were subjected to some form of water restriction.

Water-deprived sheep and camels also appear to behave in a similar manner. Apparently when nitrogen intake is low, nitrogen output is reduced and nitrogen is recycled in the body (Schmidt-Nielsen *et al*., 1958; Houpt, 1959), via the salivary glands and/or other channels. Severe water deprivation reduces nitrogen output still further, thus enhancing the value of any recycling mechanism.

In many semi-arid areas the mineral content of the only free water available progressively rises as the dry season advances, and may become so concentrated as to be unsuitable for drinking purposes. This is yet another hazard for livestock living in these areas. Tolerance to highly mineralized water can be induced, is a function of adaptation, and presumably happens in practice during the dry season in the semi-arid areas as the free water supplies contract.

The short-term effect of water deprivation on the liveweight of cattle can be very dramatic (Payne, 1965), but this may be mainly due to loss of body water. The long-term effects are not so well documented, but as water deprivation reduces feed intake it would be expected that it would also decrease liveweight gain. The experimental evidence available suggests that this is so. Payne (1965) reported that over a 2-year experimental period intermittently water-deprived *Bos indicus*-type identical twins weighed 14.9% less than their normally watered co-twins, but that the difference in liveweight gain between the two groups occurred during the first 6 months of the experiment. In this experiment the effect of seasonal changes in the quantity and quality of the forage available was far more marked than the effect of water deprivation on liveweight gain.

More recent experiments in Ethiopia, to investigate the effect of water deprivation on the productivity of *Bos indicus* cattle (Nicholson, 1986), have produced somewhat similar results.

Effect on the Nutrient Content of the Forage

Livestock in the arid and semi-arid regions have to exist for long periods on forage that is essentially mature standing hay of low nutrient value.

The low protein content, often averaging between 2 and 4% CP, and the even lower protein digestibility of this forage, is one of the major reasons for the poor performance of cattle in these regions. The reasons for this are that many of the indigenous forage plants are inherently not particularly nutritious, that the forage is usually mature when it is consumed, and that as the forage plants dry out leaf fall increases, leaving feed material with a high stem: leaf ratio. The crude fibre content of the standing hay is high as the forage plants are mature and there is evidence that environmental conditions in the arid and semi-arid tropics favour the early onset of lignification.

Livestock are therefore forced to digest highly lignified fibrous feeds, and as digestion of fibre increases the heat output, the heat load on the animal is increased at a time when it is already under considerable heat stress.

Parasites and Disease

High ambient temperatures and humidities generally provide a favourable breeding environment for internal and external parasites, fungi and disease vectors. Internal parasites are not so important in the semi-arid tropics, but external parasites usually remain very important, though their importance diminishes in the very arid tropics. In so far as the type of vegetation in a region influences the incidence of insect vectors of disease, so climate has quite dramatic indirect effects on animal production. In those regions of tropical Africa where the rainfall is sufficiently high to support a dense growth of bush, and other factors are favourable, the high incidence of tsetse fly (*Glossina* spp.) makes some forms of livestock production difficult, if not impossible. Similarly, climatic conditions that favour *Stomoxys* spp. make it impossible in a country such as Mauritius to graze livestock outdoors at certain times of the year and compel livestock owners to build relatively expensive housing to protect their animals from the swarms of flies. In other countries, such as the Sudan, the seasonal incidence of biting flies greatly influences managerial methods.

Storage and Handling of Animal Products

Most tropical climates, humid or arid, favour the rapid deterioration of stored animal products, thus increasing processing and handling costs. This indirectly affects animal production as increased processing, handling and storage charges, such as the provision of additional refrigerator capacity, may make increased production uneconomic in certain marginal areas that are otherwise suitable for the development of a livestock industry.

Adaptation

Acclimatization is the word for the complex of processes by which an animal adapts itself to the environment in which it has to live. If an animal is introduced into a new environment and the stresses on it are too great it will fail to acclimatize, its health will deteriorate and it may ultimately die. This often happens when temperate types of domestic livestock are introduced into tropical environments. Of course, climatic stress is only one of the many stresses that the temperate type of animal has to withstand in a tropical environment, other major factors being managerial, nutritional and disease stresses.

Adaptation to heat stress may be temporary or permanent and depends upon the animal either increasing its heat loss, reducing its heat production, or increasing the tolerance of its tissues to more fluctuating and higher body temperatures.

Temperate-type domestic livestock are able to acclimatize more easily to considerable intermittent heat stress than to more moderate continuous heat stress. In some arid subtropical areas of the Americas and Australia, temperate-type beef breeds such as the Hereford are exposed to very considerable heat stress during the daytime in the summer months, yet this breed thrives in these areas presumably because heat stress is intermittent in effectfalling off at night during the summer months and non-existent during the day or night during the winter months. The same breeds do not thrive in the humid tropical areas of the Americas and Australia where heat stress during the daytime in the summer months may be less, but where there is heat stress throughout the year.

Permanent acclimatization to climatic stress may be due to changes in the behaviour of the animal or to changes in physiological reactions that may or may not be inherited. Natural or man-directed selection for morphological characteristics that assist the animal to acclimatize may also take place.

Changes in the behaviour of domestic livestock are important in assisting acclimatization, and it should be the aim of good management of livestock in the tropics to facilitate these changes. Livestock become more sluggish in their movements in a tropical environment, thus reducing muscular heat production. Well-known examples of this are: bulls become more tractable in the tropics than in the temperate zone, other factors being equal; poultry are more sluggish in their movements and when standing hold their wings slightly separated or if lying down adopt an extended position; temperate-type cattle managed in the tropics graze at night and seek shade more often during the day than they would do in the temperate zone; and all domestic livestock that are not specifically adapted to arid conditions drink and use more water in the tropics than they do in the temperate zone.

Physiological acclimatization by livestock to tropical environments can take many and varied forms. These include amongst others: decreasing the body's resting metabolic rate; varying the body temperature cyclically in accordance with the ambient temperature; conserving body water by concentration of waste products in the urine and faeces; conserving nitrogen by recycling urea normally discharged in the urine; and improving tolerance to increased concentrations of mineral salts in drinking water.

Although all domestic livestock can make some physiological adaptations, what is possible varies from species to species, from breed to breed within species and from individual animal to individual animal within breeds. For example: the average tolerance for salt in drinking water is no more than 1% for cattle, 1.31.5% for sheep and 5% for camels; within the genus *Bos*, zebu cattle are able to concentrate their urine rather better than can temperate-type cattle; and if temperate-type cattle of one breed are imported into the tropics, some individuals adapt better than others. These individuals may then provide basic breeding stock for the development of a more adapted type.

Physiological acclimatization may, in the main part, be the result of hormonal activity. The basal metabolic rate, for example, is controlled by the thyroid gland, whose activity is controlled by the anterior pituitary gland which in turn is regulated by hormonal feedback from the hypothalamus. More detailed information on the role of hormones in acclimatization is provided by Yousef (1985).

Morphological characteristics that could theoretically assist domestic livestock to adapt to tropical climates include a large skin area in relation to liveweight, i.e. a small animal, together with large appendages, a pigmented skin and short, light-coloured hair. The word 'theoretically' is used because many types of domestic livestock adapted to life in the tropics are relatively large, the removal of the dewlap in zebu animals does not affect their thermoregulatory mechanisms and not all tropically adapted animals possess short hair and a pigmented skin.

Successful adaptation of domestic animals introduced into tropical environments has occurred. Examples are: the development of adapted criollo breeds of cattle throughout tropical America, the descendents of cattle imported from the Iberian peninsula of Europe in the fifteenth and sixteenth centuries; and adapted woolled sheep breeds in Thailand, Malaysia and Indonesia derived from sheep introduced from the north, probably within historical times. In the cases cited adaptation has probably been due mainly to natural selection for physiologically adaptive features over a period of at least several hundred years, with some minor assistance from man, acting as a manager.

Some knowledge of the factors concerned with acclimatization is therefore very important if deliberate attempts are to be made to breed productive animals that are acclimatized to a tropical environment. When the importation of a breed into a new environment is contemplated one method of evaluating the possibility of the breed acclimatizing has been described by Wright (1954). This consists of constructing climographs made by plotting the mean monthly air temperatures against the mean monthly relative humidities, using climate data collected in both environments. If, when the resulting points are joined, the position, shape and area of the two climographs are similar (Fig. 1.9) then there is a reasonable possibility that the breed will readily acclimatize to its new climatic environment. This type of information is useful but in no way conclusive as to whether importation of livestock to any specific environment in the tropics should be attempted. Not only should all the acclimatization factors listed above be taken into consideration, but managerial standards, disease and parasite criteria, the feed situation, prices of inputs and products and the market situation also have to be evaluated before any decision on the importation of animals can be made.

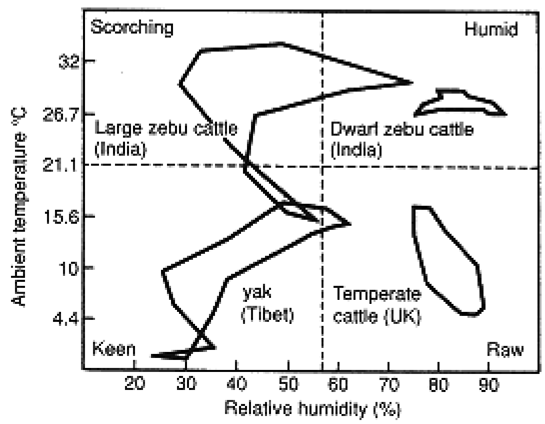

Fig. 1.9
Typical climographs for cattle in Europe and Asia
(modified from Wright, 1954).

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2
Health

Maintenance of Health

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A Definition of Health.

Health can be defined as the condition of an animal that enables it to attain acceptable levels of production within the farming system in which it is maintained. The term is relative, however, as what one producer may consider to be within a normal range and represent good health may be considered ill health by another. For example, an animal which a pastoralist would consider to be healthy and in good condition at the end of the dry season, could be considered to be unthrifty if it was maintained in a feedlot under much better nutritional conditions. Similarly, the owner of a 'minimal disease' pig herd might consider the introduction of enzootic pneumonia to be a major health disaster, whereas the same disease could remain undetected for years by the owner of a herd with lower health standards.

There are good reasons for discussing health as a concept rather than disease. The use of the word 'health' rather than the phrase 'not diseased' encourages positive thinking and is also particularly relevant in the context of this book. The term 'healthy' certainly does not imply that the animal is free from all disease agents; an animal may be infected by a potentially pathogenic agent but be unaffected by it and remain in good health for an indefinite period. For example, a cow carrying bacteria of contagious abortion in its lymph nodes may be clinically healthy and the infection may not even be detectable by serological test. To the farmer she would be normal, but to the veterinarian working to eradicate the disease she would constitute a major hazard. Also low levels of infection by gastrointestinal parasites are often undetected or tolerated by livestock owners who consider their animals to be healthy.

It is therefore necessary to distinguish between clinical disease, where there are readily observable signs of ill health, and subclinical disease, where there is production loss but no signs of disease are apparent to the observer. In the majority of production systems it is losses due to subclinical disease which make the largest contribution to total wastage. Subclinical disease is an important unrecognized source of loss in many production systems. Farmers, naturally, will only treat conditions which they can see, so their advisers have an important role in helping them reduce losses from such causes as internal parasites and mineral deficiencies.

Reasons for the Maintenance of Health

Increasing the Efficiency of Production

The definition of health used above emphasizes the financial and economic importance to the farmer of the maintenance of healthy animals. The objective of any health intervention is to avoid loss of production in order to improve the efficiency of the livestock enterprise. This should be the goal whatever the form of production. It is just as important to control foot-and-mouth disease (FMD) in order to avoid lameness in ploughing oxen as it is to avoid loss of marketable milk. The return achieved from any animal health intervention must, however, be greater than the expenditure. Livestock owners will tolerate a low tick burden if the costs of mustering and treatment are greater than the benefit received in terms of increased liveweight gain. Increasingly, farmers are expected to pay a greater proportion of the cost of medicines and services previously provided free by government. This directs the need to relate costs and benefits into sharper focus.

The view of the livestock owner derives from his own financial situation; he is concerned with the cash flow of the enterprise. It is, however, necessary for government planners responsible for designing and implementing country-wide animal health programmes to take a wider view, to consider the economic interests of society and to look in a more fundamental way at the resources consumed and generated. The farmer does not have to consider the cost of a government animal health service for which he is not charged. If administrators of a veterinary service are, however, to act rationally they need to be convinced that the whole of the cost of disease control to government and to the farmer, or to society in general, is covered by the benefits received. Many countries are reviewing the ways in which veterinary services are delivered and could alter the balance between public and private responsibilities. Such reviews should generally include a reappraisal of the economics of animal-health interventions.

Security against Epidemic Disease

Not all benefits from disease control are easily quantified. An important benefit from the control of epidemic disease is the reduced anxiety of producers whose livelihood can be threatened by the disease. Further, when the risk of major epidemic disease is reduced or eliminated, livestock owners have greater security of production. This may bring about important changes in the attitude of pastoralists. Faced with the prospect of their cattle being decimated at intervals by rinderpest and other diseases, it is not surprising that pastoralists attempt to reduce their risks by maintaining very large herds. They are very aware that old animals, which may be relatively unproductive, have survived previous outbreaks and are likely to be immune to the disease. If the threat of epidemic disease is removed, pastoralists may be able to be more selective and reduce their herds to a size that is more appropriate to the carrying capacity of the rangeland.

Improvement in Human Health

Maintenance of health in livestock benefits human health in a general way through the provision of an improved supply of livestock products such as protein of high biological value. More specifically human health benefits through the reduction of those diseases, the zoonoses, which are transmissible from animals to man. The eradication from a dairy herd of brucellosis, a disease which causes abortion in cattle, will eliminate the chance of the attendants becoming infected with a disease which in man may cause the most unpleasant effects for many years. As well as this physical benefit a further one, psychological but very real, is the removal of the fear of contracting disease from animals. This is of particular significance in the case of rabies.

Improvement in Animal Welfare

It is reasonable to suppose that unhealthy livestock are suffering and, in the case of some conditions, that they are in severe pain. There is thus a humanitarian aspect to the maintenance of health. Animals in discomfort or pain are also likely to be less productive than their healthy counterparts.

It is possible, however, to maintain highly productive animals in some intensive systems where they are subject to inhumane conditions such as severe restraint or surgical procedures. It is probable, though, that in the long term the stress imposed by such inhumane systems will predispose these animals to disease and that the systems will become suboptimal in economic terms.

Preventive Medicine and the Role of Epidemiology

If action against disease is taken only after disease has appeared substantial loss will occur before the situation is brought under control, even where detection, diagnosis and treatment are effective and rapid. Prevention is much better and cheaper than cure. For a number of serious diseases of livestock, particularly those caused by viruses, there is no specific or effective therapy. Action must also be taken to avoid the adverse effect of subclinical disease.

The livestock owner and his veterinary adviser must decide on a preventive programme that is appropriate to the nature of the production system and the disease hazards. Such a programme may be very simple, perhaps consisting only of an annual vaccination against a major disease like rinderpest, or it may be a complex preventive and treatment schedule designed and adjusted in the light of herd performance or disease risk, and implemented through routine visits to the enterprise.

Planned animal health and production services are being developed in some tropical countries in order to bring the benefits of soundly based preventive medicine to an ever widening number of producers. As well as avoiding losses due to the early recognized clinical diseases, these schemes enable some control of the more difficult to detect chronic conditions. The detection of these losses depends on the identification of production loss by measurement of herd performance and comparison with some standard. This could be a target achieved in a closely similar production system under good conditions of management and/or historic data from the farm itself. Planned health schemes, in which there is a comparison of results with targets, are more applicable to commercial and emerging commercial producers. Extension agents, however, also develop programmes for more traditional producers that can be adjusted to allow for seasonal change, market opportunities and other factors.

In animal husbandry we are rarely concerned with the health of the individual animal, but with the health of a population of animals, be it 50 000 layers in a poultry house or a single dairy cow which is maintained largely in isolation but which in various ways has contact with, and forms part of, a larger population. Epidemiology is the study of disease in populations, and together with the more traditional veterinary skills of clinical examination and treatment, it is an important weapon in the armoury available to reduce disease losses, particularly through techniques of preventive medicine. Measurement of disease frequencies and loss due to disease contribute to the setting of priorities, while determination of aetiology, modes of transmission and reservoirs of disease permit the design of effective control methods.

Epidemiology can also be defined as a study of the distribution of the determinants of disease. We mean by determinants, all those factors involved in initiating a disease, recognizing that a single causative factor such as an infectious organism may not be identifiable. It is likely that in order to discover solutions to health problems we will have to search for the determinants of disease and this requires not only investigation of a specific herd or flock but of the whole livestock production system. The modern approach to health maintenance may be considered as the systems approach applied to animal health and production. Disease is significant as a constraint to the production system and its control cannot be considered in isolation from the other components of the system and their interaction. For example, it would be very unrealistic to suggest a grazing policy for the control of internal parasites which was in conflict with agronomic practice or to recommend a labour intensive treatment of animals at a time when all members of the family were busy with the harvest.

The Epidemiological Triad

A simple diagram, as in Fig. 2.1 illustrates the system and the interactions in which the animal

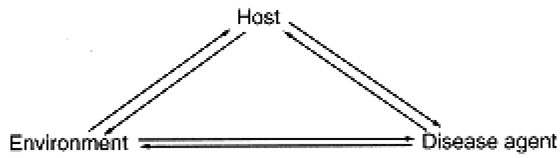

Fig. 2.1
The epidemiological triad.

or host is in contact with a disease agent and the environment within their common environment. The arrows represent interactions between the three components. The disease agent can damage the host through some disease process but this is modified by the host which may eliminate the agent through innate or acquired defences. Both host and disease agent are influenced by the environment; a well-nourished host may be better able to withstand the agent, the environment through irradiation and desiccation may be inimical to the parasite. When the host is a grazing animal it will also bring about changes in the environment which make the environment more or less favourable to the survival of the host itself and of the parasite, where this has free-living stages. The livestock owner can manipulate all of these components to his advantage by improving the health of his livestock. Management can be considered to comprise the way in which man influences all three components of the triad to achieve a production goal. To a greater or lesser extent the livestock keeper manipulates the environment that includes housing, the disease agent, and the hosts or animals in the production system. Consideration of such simple conceptual models of disease is a very useful first step in understanding the disease process and how it might be altered.

The Nature of Disease

Some Definitions.

An infectious disease is one involving the entry and development of a living organism into the body of the host. Infestation is where the organism is present on the surface of the host (e.g. ticks and lice), but the term is also used to describe invasion of the gastrointestinal tract, e.g. by helminths. Transmissible or communicable diseases are those which can pass from an infected to a susceptible animal. A contagious disease is one which is spread by contact. Venereal diseases such as *Trypanosoma equiperdum* or vibriosis are classic examples where intimate contact is required. A number of viral infections spread by the airborne route are also contagious as they require close contact due to their fragility. Skin diseases such as mange and ringworm can be spread by casual contact between animals, but the robust nature of the organisms responsible for these diseases allows them to survive in the environment, thus creating the possibility of spread by indirect contact. Objects contaminated by organisms can be a source of infection and are known as fomites.

An *epidemic* is the occurrence of a disease above its usual frequency in the population and a *pandemic* is a very widespread epidemic affecting a continent or the whole world, such as occurred when rinderpest swept across the African continent towards the end of the nineteenth century. An *endemic* disease is one which is present at much the same level in the population at all times, e.g. mange in camels or FMD in some livestock populations in the tropics.

An *acute* disease is one where the disease in the individual flares up quickly and is soon resolved either through death or recovery, e.g. blackleg or anthrax. A *chronic* disease such as contagious bovine pleuropneumonia has a much longer time scale, lasting months or even years.

Defence against Disease

The presence of a disease agent may not be sufficient to produce disease. Domestic livestock like all other living creatures have a range of defences which protect them from disease agents in all but the most unusual circumstances.

Behavioural response is one way of avoiding contact with agents of diseasethis may be a simple response such as seeking shade to avoid intense solar radiation or a more complex one implied in the instinctive ability of some animals to avoid poisonous plants.

The physical protection of the skin and its hair or feathers are a first line of defence against many physical and biological agents, as are the mucosae of the intestine and the respiratory tract. In addition, livestock may possess more complex mechanical defences such as the outpouring of tears as a reaction to irritant materials and the brushing action of the cilia of the respiratory tract in removing potentially damaging agents.

Immunity

Animals have the ability to recognize certain molecules, particularly those of proteins and complex polysaccharides, as being foreign or not part of their own metabolism. These foreign substances, termed antigens, may occur inside or on the surface of infectious organisms and the body responds to their presence by producing complex proteins called antibodies. The antigenantibody response is central to the immune reaction and if it confers protection to the animal the latter is said to be immune to the particular foreign agent. The reaction is highly specific and quantifiable so it can be used in testing for the presence of either the antigen or the antibody in order to diagnose an infection.

When an animal produces antibodies it is said to exhibit *active immunity*, but antibodies can also be acquired from an external source when the animal is said to have acquired *passive immunity*. In the new born animal one external source is its mother, while in all animals antibodies may be provided by inoculation. Antibodies of several types are recognized but the only distinction made here is between circulating antibodies carried in the bloodstream and readily available for the conduct of serological tests and the very important tissue-bound antibodies conferring immunity, particularly to body surfaces such as those in the respiratory and gastrointestinal systems.

Organisms vary widely in their ability to elicit an immune response. The virus of rinderpest, assuming the animal survives the clinical disease, is highly antigenic and cattle are immune for life on recovery from the disease. It is also highly immunogenic, that is to say that the antibody produced is highly protective. On the other hand, the virus of African swine fever is a poor antigen, infection confers no immunity and the disease may recur again and again. The virus of FMD demonstrates another variation as there are different types of the virus with different characteristics. Types A and O are generally moderately antigenic but the South African types much less so. Similar differences are found in the bacteria; some, the *Clostridia* for example, are highly immunogenic whereas the *Salmonella* are much less so.

Host responses to protozoan and metazoan parasites are complex and are discussed in the second section of this chapter.

The Causes of Disease

In historical times the diseases against which action has been taken, often very successfully, have usually been caused by highly virulent and conspicuous infectious agents against which vaccination and sanitary measures have been effective. Many diseases are, however, the result of a complex interrelationship of the animal with its environment. The term 'web of causation' has been used to highlight the interaction of the components leading to a disease process. Disease determinants affect the frequency of disease occurrence. Intrinsic determinants include the genotype, the immune status and the behaviour of the animal, while extrinsic determinants include animate and inanimate components of its environment. It is often possible to identify specific factors such as microorganisms or physical factors which are essential for the occurrence of disease. The general name given to these is disease agents.

Determination of Disease

The Host

Resistance to particular infectious agents appears to be very highly developed in some species of livestock: anthrax can affect a wide variety of mammals but birds are highly resistant; horses remain uninfected while FMD spreads through groups of cattle, sheep and pigs. It is possible, however, to break down species resistance by using large doses of the disease agent or by challenging the host through an unusual route, e.g. by injection of the disease agent into body cavities. Laboratory animals can be infected with a very wide variety of organisms in this way.

In any disease outbreak there is always a number of animals which remain unaffected. This may be because they were not fully exposed to the disease agent or were resistant to it. It must be recognized that considerable genetic variation exists in our domestic livestock so that individuals will vary in their reaction to a disease agent.

Genetic defects may act as agents of disease. A widening range of these is recognized, varying from the most extreme lethal forms resulting in death of the fetus or of the neonatal animal to those where the condition is compatible with life, such as the 'bull-dog calf' condition that occurs in several cattle breeds, splaylegs in piglets and defects of the heart and great blood vessels in many species.

The genotype of an animal may cause it to be susceptible to the effects of an agent that precipitates a clinical disease. An example of this situation is 'cancer-eye' of cattle. Hereford cattle with unpigmented skin around the eyes, grazing under conditions of high solar radiation, develop a squamous cell carcinoma of the eye. There are two or three determinants of this disease: the gene(s) for an unpigmented skin, the ultraviolet irradiation and the human manager who maintains Hereford cattle under conditions where the occurrence of the disease has been clearly recognized.

The Environment

Physical determinants are important predisposing factors. Thus rapid changes in temperature and humidity may precipitate respiratory disease and rising water table levels may bring spores of anthrax to the surface of the soil. Particularly important is the role of climatic factors in determining the risk of parasitic diseases that possess free-living stages. Soils help to determine the make-up of the biotic environment and, interacting with climatic factors, determine the availability of minerals for grazing livestock.

In grazing stock a number of conditions reduce grazing efficiency. Grazing time may be limited when livestock are required to travel a long distance to water, to seek shade at the hottest time of the day or to seek shelter from predators.

To a lesser but still significant extent there are conditions that reduce the ability of the animal to compete when managed under more intensive conditions. This is particularly the case with pigs where trough space is limited and feeding restricted.

Agents of Disease

Anything living or inanimate whose presence is necessary for the occurrence of disease is termed a *disease agent*. Agents may act alone to produce ill health, as in the case of death from drowning or from a highly infectious disease like anthrax. More frequently, agents act together with others as with a bacterial infection invading an animal's lung tissue that has been previously damaged by the ammonia present in a badly ventilated house or by a viral infection. Many diseases that prove difficult to control are multifactorial, involving a number of agents acting together or in concert. It may therefore be possible to control a disease, not by attacking the precipitating agent but by eliminating or reducing the effects of any predisposing factors.

Physical

Physical factors in the environment may act as single agents, e.g. lightning strike, or a fall. The significance of these varies widely with the nature of the production system and can be of some importance in extensive systems. There are regions in the tropics where drowning of range cattle is a major cause of loss. Losses from physical accidents are likely to be underestimated as they are rarely recorded.

Nuclear installations create new possibilities

for wide-scale damage by a physical agent. Major losses of livestock resulted from the failure of the Chernobyl plant in the former USSR when winds carried nuclear contaminants for very long distances and heavy rain then concentrated the contaminants in specific areas.

Biological.

Plants

A wide variety of pasture and forage species can become toxic to livestock under specific circumstances. The concentration of toxic substances in plants may vary through the year or with the variety. A well-known example in the tropics is the variation in the concentration of the toxin mimosine in different varieties of the valuable shrub legume *Leucaena leucocephala*.

Some poisonous plants are ingested accidentally by grazing stock, although animals familiar with such species usually avoid them; only young or newly introduced stock are normally affected. Plant poisoning may occur when feed is short, the poisonous plants are dried in hay or when animals have access to the poisonous roots of plants.

Animals

Predation occurs when one species is powerful enough to overwhelm and kill the other. Predation can be an important source of loss in extensive pastoral systems, notably through the action of large carnivores, but it is also of some importance in more intensive systems with small stock and chickens being vulnerable to predators such as the mongoose and rats.

Parasites

Parasitism occurs when one species, usually much the smaller, lives at the expense of another. The presence of a small number of parasites may have a negligible effect on the host, but if the balance between the host defences and the parasite invasiveness is disturbed disease may result. The larger parasites of the animal kingdom are a very variable group, often with complex life cycles, involving free-living stages and intermediate hosts. Of the larger multicellular parasites, the endoparasites such as gastrointestinal worms and liver fluke cause major losses. Single-celled protozoa are parasites of major importance in the tropics. Tick-transmitted haemoparasites of importance are *Theileria parva* that causes East Coast fever (ECF) and *Babesia bigemina* (redwater). Trypanosomosis, transmitted by tsetse flies, precludes most forms of livestock husbandry from many tropical regions, particularly in Africa. They are considered in some detail in the second part of this chapter.

The situation where two species are associated with very limited benefit to each other and no adverse interactions, is known as *commensalism*. A number of bacteria and fungi in the gastrointestinal tract of animals exhibit this characteristic. On the other hand, an association that is highly beneficial to both partners is known as *symbiosis*. An example of this relationship is the cellulose-splitting organisms that thrive in the rumen of ruminant livestock.

Viruses

Viruses are the smallest microorganisms and range in size from 10 to 300 mμm (1 μm = 0.001 mm). They multiply inside living cells and are generally readily inactivated by the environment but they are usually not affected by antibiotics or chemotherapeutic agents.

Mycoplasma

These agents (0.250.40 μm in size) are rather like a virus but they are extracellular. *Rickettsia* are similar in size but multiply within the cell. These organisms are susceptible to some antibiotics.

Bacteria

Bacteria are much larger than viruses, range from 0.1 μm upwards in size and can multiply outside cells, although some that cause major diseases multiply within cells. They may develop

highly resistant spores which remain a source of disease for many years. Treatment with antibiotics and chemotherapeutic agents may be effective.

Fungi

Fungi vary greatly in size, the largest being visible to the naked eye. They are often resistant to environmental influences and are sensitive to a narrow range of therapeutics.

Prions

The emergence of bovine spongiform encephalopathy (BSE) has highlighted the significance of a further class of infectious agents known as prions. Prion diseases appear to involve the uncontrolled replication of protein molecules. These are proteins normally found in the host but which have become altered, probably through changes in their shape. Much remains to be learnt of the origin and biology of prions but their apparent ability to transmit between different species, including man, is a cause for concern. Such agents may be very stable and resist the temperatures normally used in sterilization. There is no treatment at present for such diseases.

Types of Production Loss Due to Ill Health.

Reproductive Losses

Infertility or suboptimal fertility may include failure to conceive, delayed conception, abortion, stillbirth and reduced litter size in the female and poor libido and low viability of sperm in the male. This causes losses in two ways. First, production of commodities such as eggs and milk is reduced, and secondly there is a reduction in the number of potential producers recruited into the next generation, decreasing possibilities for selection and long-term genetic improvement.

An indirect source of loss is the need, when fertility is low, for livestock owners to purchase stock in order to maintain herd size. This increases the risk of introducing infectious diseases. The role of management is at least equal to that of the disease factors. Poor nutrition, inadequate hygiene and failure to observe oestrus are all factors that have to be assessed as well as the specific disease agents. The need to adopt a systems approach is therefore essential when investigating poor fertility.

Reduced Growth Rate

Clinically sick animals generally demonstrate reduced appetites, metabolize body reserves, lose weight and exhibit reduced growth rates for a variable time through convalescence and recovery. Poor growth is a frequent and often unrecognized source of loss due to subclinical disease. Unfortunately the wide range of disease conditions which lead to this situation are easily overlooked or accepted as the norm when cost-effective solutions may be available.

Delayed maturity means postponing the sale of finished stock and also causes a loss in those animals retained on the holding due to increased age at maturity for breeding or work. Economic loss is not limited to the lower turnover of the enterprise. Livestock are often reared for a specific holiday or festival when demand and prices are high. Profit margins may be reduced by selling under-weight animals or by selling them too late and when prices have fallen. In commercial operations uneven growth of batches of animals can be very disruptive and this has a particularly serious effect on very intensive systems.

Livestock recovering from acute clinical disease may grow slowly or even be stunted. The desirability of retaining these animals must be carefully considered. It may be that an animal that dies ultimately causes less of an economic loss than one that grows slowly and is eventually culled after consuming a substantial quantity of feed and utilizing for longer than normal valuable labour services and accommodation.

None the less, under certain circumstances the compensatory growth factor (see Chapter 7) may enable a stunted animal eventually to grow to the same liveweight as others in the group. This will

only occur when there has been a complete recovery from a disease and it would certainly be very unwise to fail to control preventable disease in the belief that affected animals will ultimately attain the same liveweight as their contemporaries.

Reduced Output of Animal Products

Illness causes a reduced output of those products produced through the life of the animal such as milk, eggs, wool and work. In low-input/low-output systems depressed yields often go unnoticed even where there is close contact between the stockman and his livestock. For example. subclinical mastitis may reduce the yield of an infected quarter by 20% in a lactation, but even in hand-milked herds the true significance of this situation may only be apparent if the quarters are milked separately.

Epidemic disease affecting draught animals, as when a new strain of FMD causes widespread lameness, can cause great concern when it occurs during the ploughing season. The area to cultivate is usually too large for hand operations and, if on account of the epidemic there are no working animals available for hire and there are no tractors, any delay or reduction in the area cultivated may cause serious crop losses.

Mortality

The death of an animal is the most dramatic indication of ill health and the loss of a single valuable animal may be a tragedy for the small farmer. In the case of the death of a milking cow the farmer may lose a capital asset that is difficult or impossible to replace and also lose a regular income from the sale of milk. Major outbreaks of fatal disease are still experienced all over the world and these may disrupt the local economy.

The highest mortality rates are usually observed in young and particularly in new born animals, before they become adapted to an independent life. This major wastage is often overlooked or accepted as inevitable. The death of an animal from disease, however, may not always be a complete loss. Some carcases can be used for the manufacture of fertilizer and normally a usable hide or skin is available.

Animals at the point of death are often slaughtered and consumed. Such practice provides a significant source of protein in those communities where large livestock are not generally slaughtered for food. There are, however, inherent dangers in this practice through exposure to infectious agents and toxins. These are not only due to the consumption of infected meat, because if, for example, anthrax is present those handling the meat are also exposed to risk.

Loss of Value and Exclusion from Markets

Ill health reduces the market value of the product through lowering the quality. In the case of carcases, all or part may be condemned as unfit for human consumption. This is done not only on health grounds but also for aesthetic reasons, as is the case with the condemnation of livers infested with liver fluke. Some part of the difficulty of improving this situation is that in the local market there may be little or no premium paid for quality. Mixed meat is sold at a standard price and a hide fetches the same whether clean or damaged by ticks and streptothricosis, so there is no incentive to improve production.

Outbreaks of infectious disease may result in the imposition of movement restrictions, the closing of markets and an interruption in the supply of animals to meat plants. Valuable export trade may be lost in this manner.

The Control of Disease

Objectives

Objectives will be determined by the goals of the producer and his society and they will be set against a particular production and health background.

At both national and local level, decisions, sometimes very difficult decisions, will have to be made as to whether a specific disease should be eradicated or controlled. The use of these terms can be confusing. 'Eradication' means in this

context the total removal of the disease agent and thus the disease. At the farm level, in the case of many diseases, this term has little meaning, so generally it refers to action over a considerable geographical area. It is the size of many tropical countries, poor communications and the lack of real barriers to the movement of livestock that makes eradication so difficult. 'Control' means the reduction of disease to some acceptable level, possibly but not necessarily as a prelude to eradication. The word 'elimination' is sometimes used for a situation where clinical disease is not detected by the monitoring system, but where the causative agent may still be present.

Breeding Animals for the Environment

The history of livestock development includes numerous examples of failure due to the over-simplistic solution of introducing stock that were productive in one environment into a new and quite different environment to which they are poorly adapted. The adverse effects of climate, nutrition, management and disease in the new environment then exacted a terrible toll. It should now be clear that the introduction of exotic animals into tropical countries can only lead to useful sustainable increases in production levels if this measure is accompanied by profound changes in attitude to the importance of genotype and correct management. Far greater attention must be given to using animals of a genotype which will survive not only the average conditions prevailing but also considerable deviations from that average.

In many species genetic resistance has been identified to viral and bacterial agents, protozoa and both endo- and ectoparasites, so that genetic selection is an important part of any integrated approach to animal health. In Australia the constant problem of counteracting the effects of the tick *Boophilus microplus* has led to a major change in tactics. After many years of continuous acaricide application, with ever increasing problems of tick resistance and cost, and of difficult-to-implement pasture rotation programmes, a workable solution to the problem has been found. This is the large-scale introduction of crossbred *Bos indicus* × *Bos taurus* cattle whose resistance to the tick, along with good production traits, permit successful ranching with little or no direct expenditure on tick control. Host resistance to ticks has also been extensively researched in Africa. In South Africa exotic beef breeds were observed to harbour six times as many ticks as the indigenous Africander cattle. It was found that resistance to the tick *Boophilus microplus* is directly related to the proportion of indigenous genes present in cattle and that the heritability of resistance to ticks is also higher in indigenous cattle. Crossbreds with both high resistance to ticks and desirable production traits are being developed, although the economic basis for this work is not as clearly defined as in the Australian context. Resistance to multiple host ticks, such as *Rhipicephalus appendiculatus*, has also been observed. Relative resistance to ticks may not, however, be of much benefit when the goal is to avoid tick-borne disease as very few *R. appendiculatus* ticks are required to transmit East Coast Fever.

In Africa the high financial and environmental costs of current tsetse fly control methods, that are used in attempts to control cattle trypanosomosis, have generated an intense interest in the use of trypanotolerant breeds. The N'Dama and the West African Shorthorn are breeds that exhibit tolerance to trypanosome challenge and some East African Red Masai sheep are resistant to *Haemonchus contortus*, a major cause of nematodiasis. In these breeds, however, resistance may break down when challenge is high and the use of resistant breeds may introduce other husbandry and productivity problems.

Attempts are being made to select for disease resistance in livestock breeding programmes. It is likely that this approach is most relevant where disease agents are widespread or where disease is due to a combination of factors and is difficult to define. It may be best seen as part of an integrated approach to disease control. In the case of nematodes it is suggested that the practical and economic strategy is to select animals for their ability to develop immunity, rather than embarking on long-term breeding programmes to select for genetic resistance to primary infestation. This attitude may also be valid when considering how to control other disease agents. In this respect a programme for the identification of strains of chicken resistant to leucosis has been successful, a 20-year breeding programme having produced Leghorns with high resistance and good production characteristics. It is more difficult to incorporate disease-resistance objectives in breeding programmes for larger, slower breeding species. The suggestion has been made that the heritability of susceptibility to mastitis in dairy cows is high and that selection against those that appear to be highly susceptible would be worth while at the herd level when culling and replacement decisions are being made. There is also interest in identifying 'markers' for disease resistance and in using them as one basis for selection. For example, some sheep breeds such as the Merino and the Finn Dorset, that are homozygous for haemoglobin A, are more resistant than other breeds to gastrointestinal parasites. Another marker identified is that resistance is associated with the secretion of b-lacto-globulin AB, suggesting that selection for animals carrying the gene for this characteristic would be desirable.

Surgical Procedures in Health Maintenance.

There are a number of surgical interventions practised in livestock husbandry that may or may not improve the health of livestock. Housed animals frequently injure each other with their horns and humane removal, preferably of the horn bud of the young calf, is desirable and should be a routine measure. However, it may not be a desirable practice in extensive systems when cattle may need horns to protect themselves against predators. Castration of male animals has some significance for health as it reduces fighting in the sexually mature. Removal of supernumery teats may also be a wise precaution as such teats are disposed to develop mastitis. Teeth clipping and tail amputation of pigs and beak clipping of chickens may be justified, but the need for it may also be an indication of unsatisfactory management. The amputation of the tails of dairy cattle may be convenient for the milker, but it has no advantage in the control of mastitis.

Surgery is sometimes used to correct genetic defects. For example, in the 'Mules operation', skin is excised from the hindquarters of Merino sheep in order to make them less susceptible to fly strike.

Modification of the Environment

Nutrition and Disease

Manipulation of the nutritional environment has a major role to play in the maintenance of the health of livestock. In general the well-fed animal is more resistant to disease than the poorly fed animal, being able to provide a more effective immune response and having good body reserves to help it survive clinical disease. The relationship, however, is complex. For example, it has been observed that the badly fed scrub animal may resist a given dose of the virus of FMD but become susceptible to the same dose after a period of better feeding. In some cases of bacterial enterotoxaemias, such as braxy (*Clostridium septicum*), the best animals in the group seem to succumb to the disease. In this particular case it is likely that the infection is widespread, but that the metabolic condition of the fatter animals enables the organism to reproduce and cause the disease.

It should also be noted that some managerial procedures such as dipping and transportation can be most hazardous for the better-fed animals.

Nutritional Supplementation

Large-scale supplementary feeding is not yet widely practised in the tropics (see Chapter 3), but some form of mineral supplementation has been traditional for many pastoralists.

Pastoralists often have considerable insight into the mineral requirements of their livestock and may undergo periodic treks to recognized grazing or other sources, or alternatively purchase salt and other minerals from traditional suppliers. In ranching practice mineral blocks that supply calcium, phosphorus, sodium and various trace minerals are widely used.

The Grazing Environment

Manipulation of the grazing environment can have a major impact on disease control, particularly through its effect on parasite development and the survival of the animal. Cultivation reduces the number of infectious helminth larvae on the soil to negligible levels. In dry periods, and if the stock are removed, harrowing pasture and the breaking up of faecal pads may promote the escape and distribution of infective larvae but will expose them to the lethal effects of desiccation and irradiation. High stocking levels may keep the pasture sward short enough to be unfavourable to the free-living stages of ticks.

Rotation of grazing to ensure that the parasites have died off before reintroduction of the stock is fraught with difficulties. In high-potential areas management requirements for the efficient utilization of the grazings conflict with managerial requirements for a reduction in parasite numbers. Thus rotational grazing may benefit the animal by keeping it well fed rather than by reducing the challenge of parasites.

Environmental action may be an economical way of controlling disease, in a limited area. For example, stock can be fenced out of a corner of a field where poor drainage provides a focus for the snail vector of liver fluke. On a large scale, destruction of tree and bush cover by farming activities can eliminate tsetse fly. The effect of burning grassland in relation to tick control is a management factor that has been widely debated. Although some ticks are killed it is ineffective in controlling those ticks which, since burning takes place in the dry season, have moved deep into the vegetative mat on the soil surface or into cracks in the soil.

The Housed Environment

The provision of housing for stock presents opportunities and creates problems. The health impact of housing may be as much negative as it is positive and there are occasions, particularly in development projects, when expensive housing is provided more on account of the dictates of fashion than for any real health need. Houses provide an environment in which livestock are in close contact in a restricted air space where disease organisms are protected from the lethal effects of climatic agencies. In general cheap, temporary buildings constructed from local materials are preferable to expensive permanent buildings. They are likely to be open-sided and thus well ventilated, and as they are temporary they are likely to have a short life span and can be destroyed before there is a major build-up of disease organisms. However, attention to design can benefit even the simplest local construction.

Where intensive production is planned the use of modern materials may be essential. Impervious concrete floors and rendered lower walls are readily cleaned and disinfected. Even in intensive systems, however, the use of cheap, disposable materials should be considered. For example, straw bales make excellent wall divisions for groups of individual calves. The worst scenario is an expensive and prestigious permanent, but badly designed building, expensive to modify and difficult to abandon.

The important health-related aspects of building design are as follows.

• *Location and access*. The building should be centrally sited and have good access. For example, there is no point in providing a milking parlour with an excellent floor if the access road is so rough and wet that cattle damage their feed walking to the parlour. Careful site selection can also ameliorate climatic factors, taking advantage of natural features and trees to provide shade or shelter.

• *Size*. Adequate space is essential. Minimum space standards should ensure that animals are free to rise and lie down, easily turn around and groom themselves. The larger the number housed and the larger the group size within a house the greater the disease risk.

• *Ventilation*. Good ventilation enables stock

to regulate their body temperature and dilutes and removes microorganisms together with toxic gases. It also removes moisture from the house making the internal environment less favourable for the survival of infectious agents.

• *Lighting*. Good lighting will enable any sick animal to be observed promptly.

• *Insulation and shade*. Good insulation, particularly in the roof, will reduce heat stress. Observations of animals, including zebu cattle, show how much they value shade. It is surprising how often shade is inadequate in tropical livestock yards. Local materials, supported on sturdy uprights, can provide cost-effective protection.

• *Surfaces*. Floors should allow stock to move, lie down and rise easily without slipping, but not be so rough as to abrade their feet, teats or other parts of the body. All surfaces in contact with animals should be impermeable and easily cleaned and disinfected.

All buildings should be safe, convenient and comfortable for those workers who manage the livestock.

Infectious Diseases

Exclusion of Disease

Under traditional management there is little that can be done by the individual to exclude disease agents that are endemic in the area. Pastoralists do, however, have excellent intelligence systems and will move their stock away from disease outbreaks. This carries the considerable risk that their stock may already be incubating the disease which is then further distributed. An additional risk is that severe outbreaks of a disease such as rinderpest may lead to panic selling of animals and the consequent depression of prices attracts distant buyers who may spread the disease still further. Butchers and traders can be adept at avoiding disease-control posts and resale or off-loading of sick animals by them can be very dangerous, leading to a rapid extension of the epidemic.

As systems become more commercially orientated real opportunities for the exclusion of infectious disease arise. Foot-and-mouth disease, brucellosis, tuberculosis and Johne's disease are examples of diseases where exclusion can be a helpful form of control. Physical separation from adjacent stock, even by single fencing, together with the disinfecting qualities of bright sunshine often proves surprisingly effective. If epidemic disease is known to be in the area it is even more useful to move stock away from perimeter fences. Double fencing is expensive but may well be justified to protect livestock against high risks, such as adjacent stock routes. Sometimes opportunities for providing suitable fencing are missed in developing new commercial livestock systems. Where small-scale fattening schemes are established, perhaps with the animals being tethered, very little extra organization can ensure that contact of valuable fatteners with other stock is avoided.

The introduction of new animals into a holding needs careful control and this should begin off the farm with the selection of the source of the new animals. The best protection is to purchase animals only from a known and trusted source with which regular trading has been established and from which animal health certificates can be obtained. Wherever possible a farm quarantine should be established prior to the introduction of new animals to the herd or flock. A period of 2 weeks' quarantine is satisfactory. A minimum of 1 week's quarantine should reveal if introduced stock were incubating any infectious diseases on arrival. A quarantine period also provides an opportunity for any other appropriate treatments or vaccinations to be given and for resting animals that may have been stressed by lengthy travel and marketing procedures.

Precautions should also be taken to ensure that employees do not introduce their own animals into the holding, that stray animals cannot enter and that there is no mixing with other herds at off-farm watering points.

People and vehicles visiting farms are very likely to have recently visited other farms with livestock and they constitute a real health risk.

Vehicles should be loaded and unloaded at sites where there is no danger that they will come into contact with the farm livestock.

Purchased feed can be contaminated with disease agents. Unsterilized animal material may carry the risk of salmonellosis and rodents may contaminate any type of feed with the organisms of leptospirosis. As a minimum precaution, feed should be stored in vermin-proof buildings and stock observed closely after any change in the feed.

Challenge and Hygiene

It may be possible to exclude some disease agents, but often all that can be done is to achieve a stable relationship between stock and potential agents of disease so that animals and the agents of infectious disease are in some form of balance. There are factors which favour the agent such as a suitable environment for survival and transmission or an ability to mutate to form a more virulent strain. Change in the hostparasite relationship can tip the balance either in the direction of health or of disease.

Animals may be resistant to low levels of disease agents, but will succumb if the number of disease organisms to which they are exposed, known as the 'challenge', is increased. Young or older animals introduced to a new situation can mount an immunity to a great many infectious agents provided that the challenge is not so great that they are overwhelmed before they can provide an effective response. An important way of controlling disease is therefore to limit the challenge, and this is the reason for adopting the hygienic practices listed below that help to prevent undue challenge of susceptible animals.

General Hygiene.

Potentially infectious material contaminated with the infected discharges of sick or excreting carrier animals must not be allowed to accumulate. Dead animals must be immediately removed and properly disposed of by burning or burying or by placement in a properly constructed pit. The practice of leaving corpses for scavengers to dispose of encourages the survival and dissemination of disease organisms and the scavengers themselves may become a health risk. Where breeding diseases are present special care should be taken to detect and dispose of aborted fetuses and placentas.

Disinfection

Indirect contact between batches of animals and the build-up of infection in continuously occupied houses can be avoided by the routine use of suitable procedures to move and destroy disease organisms. If carried out thoroughly in an adequately designed house, this can be highly effective. The first step is the removal of all manure, bedding and removable fittings. The building is then thoroughly cleaned with water containing a detergent by soaking and scrubbing or by the use of a power hose, if one is available. Many disinfectants are inactive in the presence of organic matter and dirt physically protects organisms, so this initial cleaning is essential. The second step is the use of a disinfectant. Care must be taken in the selection of the chemical which should be mixed and used according to the manufacturer's instructions. Very effective disinfection can be achieved against specific disease agents at low cost using readily available chemicals. Washing soda (sodium carbonate) is highly effective against FMD, for example. An excellent alternative to liquid disinfectants is a fumigating agent. Formalin, generated by the mixing of potassium permanganate and formaldehyde solution and used with suitable safeguards, is one of the most effective disinfecting agents. Animals and stockmen must be excluded from the building until fumigation is completed and the building has been thoroughly ventilated.

Disinfection of buildings with earth floors is much less effective but the numbers of disease organisms will still be substantially reduced, particularly if the building can be left unoccupied for a few weeks. Decontamination of infected yards depends on removal of infected material.

A special application of disinfection is used to reduce the transmission of the organisms of

mastitis in dairy herds. Infected milk carried from one cow to the other on the hands of the milker or through the machine is a major cause of new infections. It has been found that disinfection of the exterior of the teat after milking, by dipping it in hypochlorite or iodophores, is an effective way of interrupting transmission of the disease.

Animal-to-Animal Contact

It is important that young animals should only be exposed to low levels of challenge. However, as their immunity develops they can tolerate higher levels. This is particularly important in housed neonatal animals between which disease can spread rapidly due to high contact rates and low immunity. Young housed animals are best reared individually (dairy calves) or in physically separate groups (pig litters). Outbreaks of enteric disease, a major source of calf and piglet loss, should then be limited. As the young animals mature both physiologically and immunologically they can then be safely mixed with others.

In housing for neonatal animals solid partitions between single animals or litters should extend to the floor and faeces and urine should drain to a channel outside the pens. Respiratory disease in calf houses is less easily controlled by good housing and ventilation. Radical solutions such as abandoning the permanent accommodation and rearing the calves in temporary shelters made of straw bales may be the answer.

The problems of rearing very young animals are greatly increased where purchased animals are frequently being introduced, bringing with them pathogens to which the resident young animals have no immunity.

The risk of contagious disease is not restricted to the young or to intensively managed animals. Livestock in extensive systems are not necessarily at low risk. They are frequently crowded into corrals at night, they can have intimate contact with other cattle at watering points and they move in and out of crowded markets. Animals sent to market and then returned unsold can readily introduce disease into a holding.

Manipulating the Challenge

The control of gastrointestinal parasites is a good example of progressive exposure to challenge. Adult worms in the intestine lay eggs which are passed in the faeces of the animal to the pasture where they develop to the infectious stage and are subsequently ingested by a grazing animal. Large numbers of worms cause disease and even death, particularly in young animals. In their first grazing season young livestock should be grazed on pasture with the least number of infectious larvae, that is, pasture that has only been grazed by adults in the previous season. Under these circumstances any infection that develops and subsequent further pasture contamination is insufficient to produce disease but sufficient to act as an antigenic stimulus. If circumstances tip the balance in favour of the parasites, and if anthelmintics are available, the stockman should use them.

Strategies of this type offer effective but cheap control of some specific diseases. In the case of enzootic abortion of sheep the danger lies in the young females being challenged for the first time when already pregnant. The ideal strategy is to graze the ewe lambs with the breeding ewes prior to mating. The young sheep then suffer subclinical disease and acquire an immunity that safeguards them thereafter. Somewhat similar strategies have been used in pig units where the intestinal tracts of older, slaughtered pigs have been fed to the weaners to effect a crude form of immunization.

Endemic Stability and Epidemic Instability

Large populations of animals, often under traditional management, can survive in the presence of infectious disease agents which are potentially fatal. An example of this type of disease situation is the tick-transmitted *Theileria parva*, the cause of ECF in Africa. Regular challenge to cattle from birth by the vector tick, some of which are infected, results in a limited number of deaths and a large number of surviving, immune animals. The hostparasite balance achieved is called endemic stability, i.e. the disease is present at a fairly constant level as a result of a complex interaction of genotype, immunity, agro-climatic factors affecting the tick and tick*Theileria* interactions. Attempts to fully control the disease or the tick population may convert a stable situation into an unstable one. Tick numbers may be reduced to the point where challenge and the emergence of immunity in the cattle does not occur. Any subsequent failure of the tick control programme leaves susceptible animals exposed to a rapidly increasing and infected population of ticks resulting in an ECF epidemic. In this way, by attempting to establish full control of a disease endemic stability can be converted into epidemic instability.

Immunity

Colostral Immunity

The early survival of the young mammal is greatly facilitated by the acquisition of passive immunity from its dam. Antibodies can be passed to the young *in utero* or via the first milk or colostrum. In the case of birds, antibodies are absorbed from the yolk sac. In terms of health maintenance in ruminant animals colostral immunity is of the greatest significance, first because ruminants receive little antibody via the placenta and secondly because colostral feeding is under managerial control. The gut of the young ruminant remains permeable to the large antibody molecules for only a few hours, so young animals must obtain their colostrum within that time. In pastoral and ranching cattle systems and generally in the case of small ruminants the new born animal has free access to colostrum. In dairy cattle and camel herds, however, calves may be removed from their dams at birth and not be allowed adequate colostrum. Any young animal failing to suckle in the first few hours of life should be fed colostrum from its dam or from another female that has given birth within the previous 48 hours.

Colostrum can be delivered by stomach tube to calves and small ruminants. It can also be frozen indefinitely with little loss of potency. Antibodies are also present in soured colostrum, and its feeding should be investigated in the tropics where some simple evaporative cooling may be required. Although colostral antibodies are not absorbed by older animals it is considered that the presence of antibodies in the gut and on the mucosa protects older animals against enteric pathogens.

Antibodies are highly specific in their action so that colostrum will only give protection against pathogens to which the dam has been exposed and has immunity. Thus the offspring of a dam recently moved to a new environment may be highly susceptible to disease agents in the new environment.

Vaccination of pregnant females can be used to ensure high levels of specific antibodies in the colostrum. This has long been practised as a method of controlling colostridial disease in young lambs. The importance of this phenomenon in large-scale vaccination campaigns, as a method of providing partial protection to animals born between campaigns, should not be overlooked.

Colostral immunity is a passive immunity and provides protection for a limited time period, depending on the initial level and the nature of the antibody.

Other Forms of Passive Immunity

Antibodies occur in the globulin fraction of serum and injection of specific antisera, often prepared by the challenge and bleeding of horses, can be used to protect valuable livestock for short periods from recognized disease risks.

Vaccination

In vaccination the animal is exposed to the infectious agent or its products in such a way that the immune system is stimulated and protection against subsequent exposure to the agent results, without the occurrence of clinical disease. Bacterial toxoid vaccines are toxins produced during bacterial growth modified by chemical action. Vaccines may also consist of the disease agent inactivated by various chemicals ('dead vaccine') often together with substances which potentiate

the antigenic effect (adjuvants). Alternatively, naturally occurring or cultured mild forms of the disease agent may be used as live vaccines. A closely related technique is the infection and treatment method where the animal is exposed to the pathogenic agent, but is protected from clinical disease by the use of chemotherapy. This technique has long been used in the control of tick-borne diseases and is used for the control of ECF following advances in the identification of strains of the causative organism, *Theileria*, and development of a long-acting drugtetracycline.

The artificial stimulation of active immunity to infectious disease is one of the most powerful weapons used to maintain health. Indeed there is a danger, due to the efficiency of many widely used vaccines, to believe that the mass application of vaccine is all that is required for the control of infectious disease or that complete control of a given disease is dependent only on the production of more effective vaccines. A vaccine is only as effective as the service that uses it, and control of rinderpest in Africa, for example, despite the use of an effective and safe vaccine has suffered periodic and serious reverses. Conversely, a disease can be controlled by prompt recognition, hygiene and movement controls even if a vaccine is unavailable.

Despite setbacks it is clear that the use of vaccines has had a major impact on livestock production systems in the tropics. Indeed veterinary services have been criticized for their success, it being stated that by reducing livestock mortality overstocking by pastoralists has been encouraged. This is possibly a short-term risk as in the longer term pastoralists will probably respond to the lessened disease risk and adjust their stocking levels accordingly. Certainly the idea that the retention of infectious disease should be used as a population control measure is somewhat bizarre. There have, however, been examples in intensive livestock systems where disease control by vaccination has been so effective that supply of a livestock product has increased to the point where the markets for it have temporarily collapsed. This happened in the temperate zone with the introduction of Newcastle disease vaccination in the commercial poultry industry. Such examples are rare, but they do emphasize the need to examine the wider effects of health improvements on production systems.

The ability to manufacture vaccines for some specific disease agents varies considerably. Some disease agents generate high levels of protective antibody and exhibit little variation in field type, a single vaccine strain thus protecting livestock against any field challenge. The duration of immunity varies from many years in the case of rinderpest, to 1 year in the case of blackleg. Other disease agents are less antigenic and exhibit a range of types and subtypes. A vaccine containing several components may have to be given at frequent intervals as in the control of FMD. Indeed, African swine fever is so weakly antigenic that attempts to produce a vaccine have been unsuccessful to date.

Some disease agents rapidly change their antigenic structure, thereby rendering any response ineffective. For example, trypanosomes present rapidly changing surface antigens to the host. Other disease agents are in a sense not in intimate contact with the immune system. Gastrointestinal worms stimulate immunity very slowly over a period of months and the liver fluke infestation of sheep elicits only a weak response.

Use of Vaccines.

Vaccines need careful handling and therefore in general should only be used under close veterinary supervision. It is important that a diagnosis be established before embarking on vaccination. Ineffective vaccination is not only wasteful but also alienates producers. Where vaccination is carried out as a routine measure, livestock owners should be informed as to which disease or diseases the vaccine is effective against and that if there is a very severe disease challenge the vaccine could be ineffective.

Some bacterial toxoid vaccines are very stable at room temperature but live vaccines are more fragile. Inadequate storage, where vaccines are kept at too warm or at too cold a temperature, can result in their total inactivation. Exposure to light is also detrimental.

In using vaccines, hygienic precautions must be observed to avoid transmission of diseases by contaminated needles, production of abscesses and bacterial contamination of the vaccine. Unused part bottles of vaccine should always be discarded to avoid bacterial contamination.

Animals protected by colostral immunity may not respond to vaccination and young animals need not be vaccinated during campaigns. The age at which animals are included in the campaign must be based on local knowledge and experience. Usually the cost of the vaccine is low in relation to other costs, so that as there is no risk to the animal it seems sensible to vaccinate when in doubt and to revaccinate later.

Chemoprophylaxis

As noted in a previous section, challenge of susceptible stock can be controlled by administering, on a continuing basis, chemical agents which destroy the pathogen. The technique is of particular importance in the control of protozoal parasites, with coccidiostats being fed to poultry to control enteric coccidiosis. Incorporation of the coccidiostats in the feed has proved to be an effective and economic technique. Injection of the chemical agent is more expensive and results in fluctuating blood levels of the active compound but has found application in the control of trypanosomosis. Sophisticated methods of monitoring are used, the compound being given only when a specific proportion of the total herd exhibits parasitaemias. Oral prophylactic dosing with anthelmintics when susceptible stock are exposed to infectious larvae can be used but demands better epidemiological knowledge than is often available, if it is to be cost effective. A new labour-saving device is the incorporation of anthelmintics in boluses that are swallowed by the animal and are designed, through progressive solution, to deliver pulses of the drug at appropriate intervals. Chemoprophylaxis is best used in an integrated approach to disease control. It cannot be a substitute for sound hygiene and good husbandry.

Control of Vectors

Many major diseases of livestock in the tropics are transmitted by and develop in arthropod vectors. The control of these vectors has been a major preoccupation of tropical veterinary services for decades and considerable resources have been utilized in the building, supervision and maintenance of dipping facilities.

Tick control reduces tick-transmitted disease, but in addition livestock benefit directly as the effects of tick feeding, such as blood loss and skin irritation, are reduced. Interrupting the transmission cycles between ticks and animals demands close attention to the detailed application of acaricide. This is often essential for the maintenance of exotic stock in a tropical environment. In regions where cattle are under traditional management the intensity of dipping has only resulted in an interruption of transmission cycles in the most efficient schemes. Often dipping frequency has been too low to interrupt the transmission cycles. This may, fortuitously, have been desirable as was noted in the discussion of endemic stability and epidemic instability.

It is now more difficult to justify routine acaricide applications in tropical countries as the cost of each new generation of acaricide developed in response to resistance problems escalates. It is realized that satisfactory levels of production may be achieved by using tick-resistant cattle breeds when the environmental problems associated with dipping are assessed.

Tsetse flies act as the vectors of trypanosome parasites which, unusually among disease agents, result in the exclusion of most livestock from wide areas. Some methods of controlling tsetse flies have already been discussed in a previous section. A technique not yet discussed, that requires much less sophisticated technology than spraying and offers technical advantages at potentially lower costs, is the use of odour-baited insecticide-impregnated targets. Tsetse flies are attracted by species-specific odours over long distances and fly upwind to the target; a screen pivoted to move in the breeze. The fly alights and contacts the insecticide. The advantages of this technique include its specificity for the target

species, the fact that very little insecticide enters the environment and that it is a relatively low-level technology which could be managed by local communities. Disadvantages include the need for and cost of long-term and high-quality supervision and management, repeated servicing with imported odours and insecticide, the destruction of targets by weather, people and game and the intrusiveness of targets in wilderness areas.

Detection and Diagnosis of Disease

Rapid identification of the sick animal, greatly aided by individual marking is the first requisite for treatment and control of the spread of disease. All stockmen should be able to detect a sick animal. Regular inspection by an alert person will reveal early signs of illness such as voluntary separation of the sick individual from the group and the sick animal's failure to feed or to rise when disturbed. Animals off feed develop an empty 'tucked-up' appearance. More specific changes may be readily observed, such as an alteration in the appearance of the coat, abnormal faeces, coughing or rapid breathing, discharges from the nose or mouth and unusual swellings.

Subsequent diagnosis depends on assembling as many facts about the animal as are available. In most tropical countries recording is limited and there is a dependence on verbal accounts. In many pastoral societies, however, a great deal of verbal information will be available on both the animal and its ancestors and relatives.

Clinical examination will require that the animal is properly restrained. Injectable neuroleptanalgesics can be useful but are expensive and are certainly no substitute for the good husbandman confident in handling animals by simple means.

Submission of samples to a laboratory provides a useful but not essential confirmation of clinical diagnosis. It is the clinician who is in charge of any given case and is likely to have the greatest understanding of the whole picture and who should make the final judgement as to the diagnosis. Clearly, samples may by chance not contain the causative agent or may deteriorate in transit so much that no pathogens are found by staff in the usually distant laboratory.

This is not to discount the real need to obtain laboratory confirmation in many circumstances. Outbreaks of suspected notifiable disease, the suspected occurrence of a disease condition new to the area or where a number of disease conditions present very similar clinical pictures, are a clear indication of the need for confirmation. The veterinary field-worker must be aware of how to collect material appropriate for each condition, how to pack and consign it and how to provide full supporting information and be properly supported by the administration. The value of simply equipped field laboratories, with staff trained in the efficient recognition of a limited range of conditions cannot be overemphasized.

Treatment of Disease

Not all disease can be prevented but for a wide range of conditions effective therapy is available. Success is greatly facilitated by prompt diagnosis and treatment, and although there may be a delay in treating the first case in an outbreak any further cases should be immediately detected through close surveillance. Treatment should be kept as specific as possible and the tendency to 'polypharmacy' or the provision of many treatments at the same time should be avoided. Diagnosis by treatment is less desirable than diagnosis through examination but can nevertheless be of value. Treatment of the sick or prophylaxis of others in the group has to be done on the basis of the best judgement available. It will not always be possible to have 100% certain laboratory confirmed diagnosis. The old adage 'common conditions commonly occur' should be borne in mind by all veterinary staff from the most junior to the most senior.

In many tropical countries an extraordinary amount of medicine, often paid for in scarce foreign exchange, is wasted by inadequate storage, use of the wrong preparation, treatment of animals which are most unlikely to benefit and incorrect routes of administration and dosage. The medicine label should always provide recommendations for storage and a maximum shelf life under good storage, but such recommendations are only of value if there is confidence in the handling of the drug since it left the factory gate. Generally drugs require cool storage conditions out of the direct sun and at a low humidity. Instructions for the use of drugs should be read, reread and followed precisely. Records should be kept of animals treated, dose used and the batch number of the drug. The liveweight of animals needs to be estimated as accurately as possible to avoid wasteful or dangerous overdosing and ineffective underdosing. A course of treatment is often required and the temptation to stop treatment prematurely due to an early response should be resisted. Long-acting forms of drugs and labour-saving formulations such as the pour-on pesticides may appear expensive but should be appraised in the light of the labour they save.

It should be remembered that the first rule of medicine is 'do no harm'. This refers not only to the side-effects of the drug but also to the safety of the animal being treated. Drenching or the dosing of animals with fluids by mouth can be perfectly safe provided the animal is not already comatose, is properly restrained and is encouraged to swallow. Drenching guns should not be forced back into the pharynx, causing physical injury or later abscessation. Good techniques should be observed with injections to avoid abscesses and inadvertent administering of drugs by the wrong route. Animals should not be put through plunge dips when thirsty or exhausted.

Veterinary medicines are susceptible to adulteration and other abuses. Only drugs in their original packing should be accepted. It should also be remembered that tablets and boluses are more difficult to tamper with than liquids. Workers should become familiar with the normal presentation and appearance of drugs and refuse to use any which appear unusual. In general, drugs should be always kept in their original containers and it is dangerous to store other chemicals in containers which originally held medicines. If there is no option all the original labels should be removed and new, indelible labels affixed. Drugs obtained from unknown manufacturers may be ineffective or even dangerous and should always be viewed with suspicion. Drugs from major suppliers may appear more expensive but are likely to be subject to proper quality control, and if there is need to seek advice or complain the large firm with a reputation to protect is likely to be responsive. This does not mean purchasing products only from international corporations. Properly controlled local manufacture can offer good quality at low cost, the major difficulty for most countries being that the small size of the local market often results in high production costs.

A major concern in the use of therapeutic agents is the emergence of infectious agents which have become resistant to a previously effective treatment or preventive medicine. This is well known in regard to bacteria and is of major importance in the treatment of mastitis and enteric infections. Resistance to pesticides by ticks and to anthelmintics by gastrointestinal nematodes is also of practical importance. When, however, the efficacy of a treatment is observed to decline suddenly a careful investigation of how it is being used may reveal management failings, not resistance, as the real cause. Animals may simply not have been treated, the wrong dose may have been given or poor storage may have affected the active principle. For all medicines, the right dose must be administered over the correct time period as indicated by the manufacturer. Laboratory investigation can reveal bacterial resistance to antibiotics, the demonstration of resistance in ticks is more specialized and is not practicable in the case of helminths. The guidance of a clinician experienced with local conditions should always be sought.

Supportive treatment is used as an adjunct to specific therapy or alone where no specific remedy exists. In viral infections antibiotics may be of value in controlling secondary bacterial infection. Vitamins have their place and are generally safe, but some other pharmacologically highly active substances, such as corticosteroids, should only be administered by qualified veterinarians.

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The value of nursing cannot be overemphasized. Sick animals are too often left to lie in the dirt in full sun or on the wet ground. Where possible this should be corrected and fresh feed and water be supplied at regular intervals. The animal should be isolated not only where infectious disease is present but to avoid bullying or treading. Very severe problems are faced by the recumbent large animal due to its posture being abnormally fixed. Blood supply to organs may be inadequate, fluid may collect in a lung and bloat may occur. This may be alleviated by turning the animal regularly, say five or seven times a day so that successive nights are spent lying on opposite sides of the body.

Further Reading

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Parasitology

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Strictly speaking, a parasite can be considered to be any living creature which obtains benefit from living in or on another species, which it may harm. It has become the convention, however, that so far as domestic livestock are concerned, the subject of parasitology deals with three major disparate groups of animals. These are the single-celled protozoa, the helminths (parasitic worms) and the arthropods that have adopted the parasitic way of life. Many, but not all, of these parasites are of economic importance and a number attain particular importance in domestic animals in the tropics and subtropics and are a major constraint on animal production. Others are zoonotici.e. they are parasites of human beings as well as of animalswhile yet others are so well adapted to their hosts that they cause very little damage and so are of little practical importance unless their presence is both obvious and unacceptable to their host's owners.

It is only possible here to give a brief overview of the many different disease conditions associated with parasites. Nevertheless, the three main groups of parasites of domestic livestock are so different from each other that, even to give them brief consideration, it is necessary to consider their importance, bionomics, control and treatment separately. Other information on all the parasites discussed in this chapter, and on those which are less commonly encountered or of less economic importance, can be found within the 'Further reading' texts given at the end of this section.

Helminths

This grouping, which arises mainly from the old idea that all 'worms' are closely related to each other, includes two very different subgroups, the roundworms and the flatworms. The parasitic roundworms include the nematodes, the cause of well-known diseases such as haemonchosis or ascariosis, and the thorny headed worms, of which only one species is of serious veterinary importance, namely *Macrocanthorhynchus hirudinaceus*. This parasite is the large thorny headed worm that occurs in the small intestine of pigs mainly in the tropical parts of America and East and Southeast Asia. Relatively few roundworms have complex life cycles with more than one host. In contrast, all the parasitic flatworms have such life cycles. These parasites comprise the flukes or trematodes, which cause diseases such as fasciolosis and schistosomosis, and the tapeworms or cestodes. The latter are, on the whole, rather less pathogenic but they do include one very important zoonotic parasite, *Echinococcus*, the larvae of which cause hydatid disease in man and other mammals.

The adults of all the helminth parasites are very fecund, the females or hermaphrodites, as the case may be, producing many thousands of eggs per day. Very few of the larvae which hatch from these eggs survive and give rise to an adult worm in another host, but the very large numbers of eggs produced ensure that some will do so. This renders helminths very difficult to eliminate.

Another feature which is common to most helminths is that the diseases that they cause are rather ill-defined, resulting in such non-specific signs as ill-thrift and sometimes anaemia or diarrhoea. Hence these diseases are easily confused either which each other or with other common conditions, notably malnutrition (Fig. 2.2). Their importance arises more from this loss of condition and from the economic consequences of having to adopt control measures which frequently involve nutritionally suboptimal use of grazing land, than from any associated mortality.

Accurate diagnosis of helminth diseases always requires careful consideration of the clinical signs and the surrounding circumstances (the 'history'), such as the age of the animal, the season, the recent weather, the grazing routine, recent and routine treatments and knowledge of the parasites which commonly occur in the area.

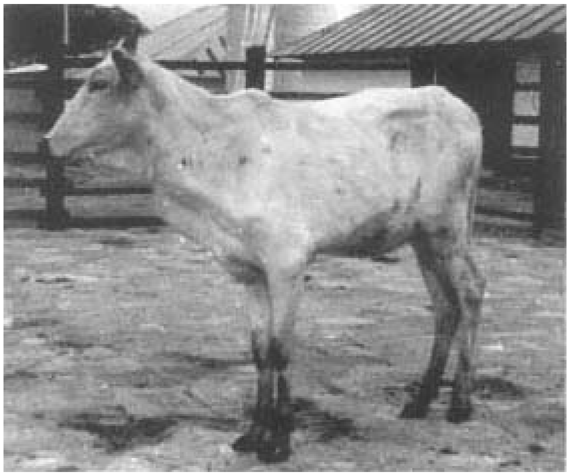

Fig. 2.2
A White Fulani heifer in poor condition. This animal was suffering from chronic fasciolosis but it would not be possible to diagnose this from the clinical appearance alone as malnutrition or other diseases such as haemonchosis or trypanosomosis would affect the animal's appearance.

To this may be added other investigations including relatively simple procedures such as a post-mortem examination with recovery, identification and enumeration of the parasites. Other useful tests may require samples of blood or faeces (Fig. 2.3) to be submitted to a properly equipped laboratory.

There are sufficient biological differences between the main types of helminths, and hence in the way in which they may be controlled, as to require them to be considered separately.

Nematodes

Apart from the relatively few zoonotic species, these parasites are mostly of importance because they impair the growth rate of their hosts, though some are capable of killing their hosts, particularly if these are poorly fed. Most of the parasitic nematodes inhabit some part of the gut of their host, although there are important exceptions, notably the filarial worms which are located in the blood vessels or subcutaneous spaces. Some of the nematodes in the gut, notably *Haemonchus*, and the hookworms, such as *Bunostomum*, deliberately suck blood, and a major part of the pathology caused by these

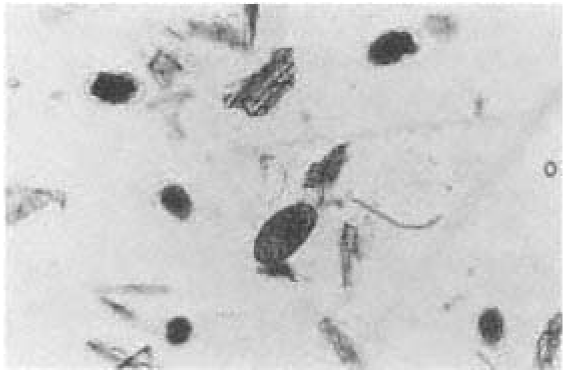

Fig. 2.3
Helminth eggs from the faeces of a sheep. The large egg is clearly that of *Fasciola* and is very distinctive. The smaller eggs, however, can only be defined as being those of a strongyle or trichostrongyle as there is no simple method for distinguishing between the eggs of most species of these nematode parasites.

parasites is related to the resultant anaemia. Most nematode parasites, however, do not suck blood, the impaired growth rate of the host mainly arising from two other causes. Firstly, infected animals tend to have a reduced appetite and, secondly, the damage to the lining of the stomach or intestine both increases the loss of plasma into the lumen and, in the case of the stomach, reduces its ability to produce the hydrochloric acid needed to permit the action of pepsin on dietary protein and to kill most of the microorganisms ingested with the food. In heavy infestations this can lead to increased peristalsis and result in scouring, with a consequential further impairment of the digestive process. Even in lighter infestations, the formed elements which leak through the damaged mucosa into the lumen of the gut have to be broken down into their constituent molecules (e.g. amino acids, etc.) before they can be reabsorbed. They must then be resynthesized (e.g. into the plasma proteins), so placing a strain on the metabolic processes and reducing the host's ability to lay down further muscle and to grow.

Other species, notably but by no means only, the lungworms such as *Dictyocaulus* undergo a somatic migration whereby the larvae leave the gut and move around the host's body for a period prior to moving to the site where their adult forms will develop. In some cases (e.g. some of the hookworms and the large strongyles of horses) this means returning to the gut. In others, such as the lungworms or *Stephanurus* the kidney worm of pigs, the adult develops at a different, characteristic site. During their migration and/or at the site at which they mature such parasites may cause considerable damage, including verminous pneumonia and verminous arteritis (e.g. the so-called verminous aneurysm caused by *Strongylus vulgaris*, one of the large strongyles of horses). However, most of this damage is related more to the host's reaction to the presence of these large foreign bodies than to anything that the parasite itself does. This applies even more to the unusual nematode *Trichinella*, the minute adults of which occur in the intestine but are virtually innocuous. The pathology of the disease called trichinosis results from the host's reaction to their larvae which encyst in the muscle of the same host.

Most of the gastroenteric nematodes lay eggs which are passed out in their host's faeces. Outside the host they either develop to the infective stage within the egg (e.g. the ascarids) or they hatch out before doing so. Most of the species whose larvae hatch out outwith the host pass through two moults before reaching the infective 'third stage' larva. These species include the important strongyle and trichostrongyle parasites of domestic ruminants, horses and pigs.

Despite this major difference in their life cycles, there are a number of important ways in which all these helmiths which have non-parasitic stages in their life cycles interact with the environment. However, there are also important differences in their bionomics which depend on the physiology of the individual species. All the free-living stages have an optimum range of temperature for their development and all of them are killed by desiccation, direct sunlight or by temperatures that are too high. Accordingly, under any natural circumstances, the vast majority of the eggs and larvae of any of these species die before they can infect another host. This is why these parasites need to be so fecund. By producing many eggs they increase the chances that some of their offspring will attain another host.

Larvae that reach the infective stage within the egg, such as those of *Toxocara vitulorum* of cattle, *Ascaris suum*, or the whipworms *Trichuris* which occur in the caecum of various mammalian hosts, are better protected against the adverse effects of the external environment, notably against drying out. However, they have to rely entirely on chance as to whether they are ingested by a suitable host. Under suitable cool, moist conditions, such larvae may survive within their eggs for months or even years and still be infective for a new host. Conversely, the larvae of those helminths that hatch outside the host may be able to move to a position where they are more likely to come into contact with a new host. The price they pay for that is greater exposure to the effects of wind, weather and temperature. In general, and within physiological limits, higher temperatures increase both the development rate and the mortality rate of the larvae, whereas desiccation kills them.

So far as nematodes are concerned, global climates therefore all fall into one of three main types (Table 2.1). Those types in which the favourable periods for the free-living stages of the nematodes are relatively warm tend to be suitable for a different range of parasites (e.g. *Haemonchus, Bunostomum* and other hookworms, some species of *Oesophagostomum*, etc.) to those for which the favourable period is relatively cool (e.g. *Ostertagia, Nematodirus, Chabertia*, etc.). One result of this is that the same nematode parasites tend to be prevalent in the favourable winter season in subtropical areas with a winter rainfall as are prevalent in the summer in temperate climates. Human activities, such as the use of irrigation in arid areas, confining cattle into small areas such as night pens or trading posts, or nomadic migration tend to extend the times in which grazing animals are feeding in potentially infective areas. Indeed, a case may be made for the proposition that most helminth disease, as opposed to helminth infestation, results from human interference with the natural habits of the hosts. Altitude is another factor which can markedly affect the distribution of these helminths. For example, *Dictyocaulus viviparus*, the lungworm of cattle, which is normally considered to be restricted to more temperate climates, has been reported to cause disease in many highland tropical areas, especially those to which exotic cattle have been imported from Europe.

Larvae located at the centre of faecal masses are relatively well protected against the adverse external environment. Furthermore, the local deficiency of oxygen retards their development. As a result of both these effects such larvae may survive through quite long periods of hot dry weather and then, when the rains come, be released in large numbers and rapidly complete their development. Bovine faecal masses provide such larvae with better protection than the smaller ovine or caprine faecal pellets. This protection is not sufficient to allow the larvae to survive through a long adverse season in which the faecal mass dries right out. Instead, for some of the most important species (e.g. *Haemonchus* and *Ostertagia*), an alternative phenomenon has evolved, similar to that seen during the winter in

Table 2.1 The interactions between helminths and climate.

Suitability for helminths	Climatic type	Description	Most favourable season(s)
Permanently unfavourable	Polar	Too cold	None
	Cool winter rainfall	Cold, wet winter Hot, dry summer	Spring and/or autumn
	Desert	Too dry	None
	Savanna	Hot with long wet/dry seasons	Rains
Intermittent	Warm winter rainfall	Cool, wet winter Hot, dry summer	Winter
	Cool temperate	Cold, wet winter Cool, wet summer	Summer
	Warm temperate	Cool, wet winter Warm, wet summer	Winter and summer
Permanently favourable	Humid tropical	Always hot Always moist	Throughout year

temperate areas. In this, the larvae undergo a period of hypobiotic inhibition within the host. Their development is suspended for several months, only recommencing shortly before the advent of the next favourable season. Such hypobiotic larvae do little or no damage to their hosts. Thus, they not only increase the chances of both their host and themselves surviving through the adverse season, but also ensure that there are plenty of eggs produced at the time of year when there are likely to be relatively large numbers of susceptible young hosts grazing on the new, luxuriant pastures. Strains of some of these species which are present in areas without such a long adverse season do not usually show this phenomenon of seasonal hypobiosis to any marked degree. However, there is some evidence that they may do so to a small extent at the height of a monsoon season, when their eggs or larvae are most likely to be washed away.

Species which do not undergo this process of hypobiosis such as *Mecistocirrus*, the hookworms (*Agriostomum* in cattle or *Gaigeria* in small ruminants), and the large intestinal nodular worms (*Oesophagostomum radiatum* in cattle and *O. columbianum* in small ruminants) may be restricted to, or be much more prevalent in, climates in which the external environment is always relatively favourable for their survival. Prolonged periods of migration within their hosts, as with the ascarids or the large strongyles of horses, may also serve to carry the parasites through periods of adverse external climatic conditions. Some of the species which undergo a somatic migration (e.g. the ascarids *Toxocara vitulorum* of cattle and *T. canis* of dogs and some of the hookworms) have also evolved the ability to pass from mother to infant, either across the placenta or in the colostrum or milk. Their larvae build up within the mother's body by infection from the external environment until she has reached the correct stage of pregnancy when they are mobilized and pass to the placenta and the mammary gland.

The filarial worms, such as *Onchocerca* or *Stephanofilaria* and the eyeworm *Thelazia*, avoid direct exposure to the external environment by the use of arthropods as intermediate hosts. During the last half of the twentieth century, the control of these parasites has been largely dominated by the use of modern anthelmintics. However, the widespread occurrence of resistance to the available anthelmintics is forcing a reappraisal of their use. Side resistance (where a strain of a particular parasite is resistant to two anthelmintics of similar action, whether their chemical structure is similar or not) between anthelmintics with the same or similar modes of action is the rule and it is important to use all such drugs in ways which will optimize the balance between cost and efficacy, delaying the onset of such resistance and potential damage to the environment. Unfortunately, there are good theoretical grounds for considering that the more effectively an anthelmintic is used the more quickly resistance will arise, and also that it is unlikely that any effective anthelmintic will be developed to which resistance does not sooner or later develop. There are by now no anthelmintics on the market to which resistance has not been demonstrated. It is particularly desirable to delay the onset of resistance to those anthelmintics which are effective against the widest range of species. Thus, if it is known that the blood sucking nematode *Haemonchus* or the hookworms are the major pathogen in any outbreak, the use of a drug with a more limited range of action, such as disophenol, presents advantages, especially if the strain of nematodes present is resistant to the more widely used anthelmintics. On the other hand, only certain anthelmintics, including the more modern benzimidazoles and the macrocyclic lactones, are effective against hypobiotic larvae.

Other appropriate methods of control are always worth considering as they may be less costly and may be able to stave off the onset of drug resistance. These include zero grazing, in which the fodder is cut and carried to animals kept in stalls or pens, and controlled grazing, with or without additional strategic anthelmintic treatments. Zero grazing is particularly appropriate for use with young animals before they are fully able to develop an immune resistance to the parasites, with valuable animals and in areas where labour is cheap.

The simplest form of strategic approach to control is a 'dose and move' routine, whereby the animals are moved onto a clean pasture following dosing with an anthelmintic that is likely to almost eliminate the parasites, so retarding the contamination of the new pasture. This can be very effective, especially if it is done at the most appropriate time of the year, such as after a prolonged dry season, when clean pastures may be readily available. However, such procedures are by no means costless, demand that the stock owner controls the use of the land and, where anthelmintic treatments are involved as in 'dose and move' routines, may be more likely to result in the onset of drug resistance than less effective, relatively random, tactical treatments. The widespread concept that animals should not be allowed out to graze before the dew has dried off may be related to the fact that heavy infection with parasites such as *Haemonchus* are more likely at that time. It is also good practice to avoid grazing animals on irrigated crops until they have been thoroughly dried out. Indeed, failure to do this can, within a matter of weeks, result in outbreaks of disease even in areas where the climate is inimical to the free-living stages of the helminths throughout the year.

Trematodes.

Parasitic trematodes or flukes are mostly flat and leaf-like, and hermaphrodite, although there are exceptions, notably the paramphistomes (the conical rumen flukes) and the schistosomes (the blood flukes, which have separate males and females). All of them have at least two hosts, the second, in which extensive asexual reproduction occurs, always being a snail. Some of them also have a third host, which may be of a wide range of species and in which reproduction does not occur.

The most important of these parasites in domestic ruminants is *Fasciola*, the large liver fluke, of which there are two main species. These are *Fasciola gigantica*, which is primarily a parasite of cattle in warm climates, and *Fasciola hepatica*, which mainly occurs in temperate areas and for which sheep are the optimal host. However, *F. gigantica* also infects sheep and goats, in both of which it is very pathogenic, and *F. hepatica* also infects cattle and occurs in cool highland tropical areas. Following infection, the flukes migrate across the body cavity and into the liver parenchyma where they remain for several weeks before passing into the bile ducts and maturing. These flukes are blood suckers and the most characteristic sign associated with the more common chronic form of fasciolosis is anaemia, together with ill-thrift (Fig. 2.2) and a reduced concentration of albumen in the plasma. Very heavy infections may give rise to relatively acute forms of the disease in which the clinical signs reflect the damage to the hepatic parenchyma. There may also be sudden death from severe haemorrhage leaking from the damaged liver, through the parenchymal tracts made by the flukes, and so into the bile ducts.

Both these flukes (*F. gigantica* and *F. hepatica*) use a snail of the genus *Lymnaea* as their second or intermediate host. *F. gigantica* uses a large lymnaeid water snail of the *L. auricularia* type (which may have various other names such as *L. natalensis*, commonly used in Africa), which is usually found in gently flowing, well-aerated shallow water, such as on the banks of irrigation outlets or on the edges of ponds and small lakes. *F. hepatica*, on the other hand, most often uses smaller lymnaeids, such as *L. truncatula*, which are mostly found on wet mud flats rather than in water. The eggs from these flukes hatch to release free-swimming ciliated miracidia, which must find and penetrate a suitable snail within about 12 hours. Within the snail, the miracidium rounds off to form a sporocyst within which several of the next stage, called the redia, then develop. Bursting out of the sporocyst, each redia may develop daughter redia internally so that there is still further multiplication. Eventually, a number of the final stage within the snail, named the cercaria, develop within each redia and are released, firstly into the body of the snail and then into the external environment. This stage is also free-swimming but, instead of directly seeking a host, they encyst, usually on vegetation in the water, to form the metacercarial cysts.

This is the form which is infective for the final host.

The best means of controlling fasciolosis is usually to attempt to ensure that the animals do not graze alongside infected water courses or ponds, or in other areas where the snails are likely to be found. Treatment with modern trematocides such as the unusual benzimidazole drug, triclabendazole, is effective and has been used strategically to virtually eliminate *F. hepatica* from farms. However, this demands good control over the land and has not so far been used against *F. gigantica*. Older trematocides, such as rafoxanide or oxyclozanide, are also effective against the adult flukes. Control methods which involve using molluscides, such as copper sulphate or niclosamide, against the snail hosts can be effective but demand very careful application and are contraindicated on environmental grounds. It is often better to drain the contaminated area, if this is financially feasible, although again this can have unfortunate environmental consequences. Keeping drainage channels in irrigation schemes free from weeds is also helpful.

Paramphistomes of various species are very common in ruminants in tropical areas. Their life cycle outwith the host is similar to that of *Fasciola* although the intermediate hosts are different snails, such as *Bulinus*, and many more smaller cercariae are produced. The metacercariae excyst in the ruminant's abomasum from where the immature flukes migrate back to the preferred site for the adults, around the reticulo-ruminal junction. Most infestations are entirely non-pathogenic but heavy infestations in calves or sheep may cause a very severe, even a fatal, watery scour in which the small flukes can be seen.

The schistosomes, which are related to the species which cause bilharzia in humans, are also common in tropical countries; one species, *Schistosoma japonicum*, is a zoonosis in Eastern Asia. Schistosomes have a somewhat different life cycle as there is no redial stage and the fork-tailed cercariae infect the next host directly by skin penetration. The adults of most schistosomes, including *S. bovis* of cattle, are located in the portal and mesenteric veins, from where their spined eggs pass on to the liver and intestinal wall. There they cause characteristic granulomatous lesions before some of them erode out into the lumen. It is this stage which causes most of the manifestations of the disease. The adults of one species, *S. haematobium*, occur mainly in the veins around the kidney and bladder and their eggs are to be found in the urine.

There are also a number of other trematodes which are parasites of domestic animals but are of lesser importance, usually because they are less pathogenic. These include smaller liver flukes of relatively low pathogenicity, such as the two species of *Dicrocoelium* which are common in ruminants, especially in arid areas. The related pancreatic fluke, *Eurytrema*, is relatively common in ruminants in Eastern Asia and may be the cause of ill-thrift, especially in sheep. A number of other trematodes occur in the intestines of pigs in Southeast and Eastern Asia, including *Fasciolopsis*, which also occurs in man.

Cestodes

The adult anoplocephalid tapeworms, which occur in ruminants and which all use oribatid mites as their intermediate hosts, are of relatively low pathogenicity. Indeed, it is questionable whether these parasites, such as *Moniezia*, *Avitellina*, *Thysanosoma* and *Stilesia*, merit treatment or control.

Conversely, some of the taeniod cestodes, such as *Taenia saginata* and *Taenia solium*, the larvae (cysticerci) of which occur in the muscles of cattle and pigs respectively, are of importance because they are zoonoses. The large adult tapeworms live in the intestine and the larvae of *T. solium* in the musculature of their human hosts. Other taeniod cestodes such as the large cystic coenurus larvae of *Taenia multiceps*, which locate in the brain of sheep, are themselves pathogenic or impair the value of meat by their presence. None of these parasites, however, are particularly restricted to the tropics.

Echinococcus granulosus is a parasite of dogs whose large larval stage occurs in a wide range of mammals, including humans, cattle and small ruminants. However, the larvae of different varieties of *Echinococcus* are to be found in different intermediate hosts and not all varieties are zoonotic. Conversely, some of them, notably one variety which occurs in parts of East Africa, are commonly associated with human infections.

Protozoa

For practical purposes, most of the important protozoal parasites of domestic animals fall into two main groups. Firstly, there are those which live in the blood, the haemoprotozoa, which include the flagellate trypanosomes and the piroplasms. Most of these parasites have life cycles that involve intermediate hosts, which act as vectors, many are particularly associated with tropical climates, and some cause diseases of major economic importance. Classic methods of diagnosing protozoal diseases and identifying the parasites involved are still widely used, especially in acute cases. However, serological and molecular diagnostic procedures, such as the polymerase chain reaction (PCR), are becoming more widely adopted for diagnosis, identification and surveys.

Secondly, there are those protozoal parasites which have at least some of their stages in the host's intestine. These parasites do not always require an intermediate host, although some of them have very complex life cycles which may include the development of cysts containing asexually generated forms within a wide range of intermediate hosts.

Trypanosomes

The trypanosomes are extracellular, flagellate, motile protozoa, which also fall into two distinct groups. Firstly, there are those species (the salivarian trypanosomes), *Trypanosoma brucei*, *T. congolense*, *T. simiae* and *T. vivax*, which characteristically use tsetse flies of the genus *Glossina (q.v.)* as their intermediate hosts, developing within the insect's salivary glands and/or mouth parts. This restricts these species to those parts of Africa south of the Sahara in which tsetse flies are present. However, some closely related trypanosomes have developed the ability to use mechanical transmission on the mouthparts of biting flies. This has enabled *T. vivax* to become endemic in parts of South America, the Caribbean and Mauritius, while *T. evansi* is found throughout North Africa and tropical Asia. In tropical Africa, *T. vivax* continues to be mainly transmitted by *Glossina*, while *T. evansi* is always transmitted mechanically. One other species is transmitted during coitus and is most commonly found in the fluids associated with the genitalia. This is *T. equiperdum*, which occurs in horses in many parts of the tropics and subtropics and is morphologically identical to *T. evansi*.

The severity of the disease caused by trypanosomes varies widely with the host and with the parasite. Some combinations, such as *T. brucei* in cattle or *T. congolense* in pigs, cause relatively little harm to the hosts, whereas others, such as *T. congolense* or *T. vivax* in cattle or *T. simiae* in pigs, may be fatal within a few weeks. The more common chronic disease is characterized by loss of condition (Fig. 2.4), a relapsing pyrexia and anaemia, and is associated with an immunosuppression. An increased frequency of

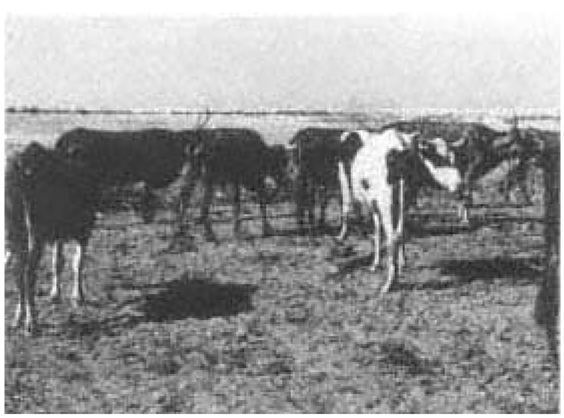

Fig. 2.4
Botswana cattle in poor condition as a result of
trypanosomosis. The disease might well be suspected

as it is prevalent in the area in which the cattle are grazing. However, the clinical signs cannot confidently be distinguished from those of malnutrition or gastrointestinal helminthosis.

abortion and stillbirth occurs even in trypano-tolerant cattle. Diagnosis of the acute disease is based on the clinical signs, history and the demonstration of the parasites in the blood.

Surra, the disease caused by infection with *T. evansi*, is of importance in camels, horses, cattle and buffaloes. The susceptibility of the different hosts appears to vary geographically. Thus, in the Sudan, the disease occurs mainly in camels, which may become febrile, anaemic and emaciated, and may die within a few weeks of infection or, in contrast, may develop only a mild protracted infection. On the other hand, epidemic outbreaks of disease have been reported in cattle and buffaloes in South, Southeast and East Asia. The animals showed the characteristic signs of trypanosomosis and high mortalities ensued. Outbreaks of disease are often associated with the movement of animals, either from areas in which *surra* does not occur or from one endemic area to another.

In much of Africa, trypanosomosis is endemic in wild ruminants and Suidae in which it does not cause disease. The presence of this disease, however, renders the rearing of cattle impossible over large tracts of land, particularly where *Glossina morsitans* is prevalent. Some breeds of African cattle, notably the N'Dama and the West African Shorthorn but also some minor strains of the Boran, can tolerate relatively heavy challenge with trypanosomes.

Despite the importance of trypanosomosis in so many parts of the tropics, for commercial reasons, no new drugs have been marketed within the last 40 years. Some new drugs are at present in the early stages of development but several of those that were effective and in common use have been withdrawn. Added to this is the fact that many strains of trypanosomes have become resistant to the available drugs.

Control methods used against trypanosomosis have included reducing the contact between cattle and potentially infected wild animals, reducing the population of vectors, principally by destroying their habitats, and by prophylactic use of drugs. All of these methods required constant application and have deleterious environmental consequences. The introduction of methods based on the use of permanently sited biconical traps impregnated with synthetic pyrethroid insecticides, which both attract and then kill the tsetse fly vectors, and to a lesser extent the use of similar insecticides as pour-on preparations on the cattle, have provided relatively environmentally friendly control methods, although these too will be rendered less effective as the flies become resistant to the insecticide.

The second major group of trypanosomes, the stercorarian trypanosomes, use various arthropods as their intermediate hosts, being transmitted when lesions in the mammalian host's skin are contaminated by the arthropod's faeces. Most of these trypanosomes are non-pathogenic but *T. cruzi* is a zoonotic parasite which is transmitted by blood-sucking triatomid bugs, is infectious for dogs, among other hosts, and causes a serious myocardial and neurological disease (Chagas' disease) in humans in South and Central America. The disease is best controlled by controlling the vector. The large, non-pathogenic species *T. theileri*, which is found widely in cattle, is another member of this group and is transmitted by tabanid flies.

Leishmania is another common zoonotic parasite which is found throughout the tropics and subtropics. It is closely related to the trypanosomes but does not have an external flagellum and uses sand flies (*Phlebotomus*) as its intermediate host. *Leishmania* is commonly found in dogs and rodents, from whom it may pass to humans. It causes very recalcitrant cutaneous and visceral lesions. Treatment tends to cause regression of the lesions but without completely eliminating the parasite.

Piroplasms

The two main genera of piroplasms are *Babesia* and *Theileria*. Each of these includes various species, some of which are restricted to the tropics, while others are more widely distributed. The intermediate hosts of these intracellular haemoprotozoa are ticks, the species of tick used being characteristic of the species of piroplasm and largely delineating its geographical distribution.

Babesia are to be found within the host's red blood cells. The species which occur in cattle are of the greatest economic importance, although most domestic animals are hosts for one or more species of *Babesia*, and some of these, such as *B. ovis* in sheep, are pathogenic. Of the four species in cattle, *B. divergens* and *B. major* are not tropical parasites, *B. bigemina* is a major cause of disease throughout the tropics and subtropics, while *B. bovis* is rather less widely distributed but of somewhat greater pathogenicity. Various species of the one-host tick *Boophilus (q.v.)* form the main intermediate hosts for both *B. bigemina* and *B. bovis*.

Acute babesiosis is associated with severe anaemia (Fig. 2.5), inappetence and jaundice, together with haemoglobinuriathe classical 'redwater'. Adult animals are more susceptible than calves and calves borne into an infected area rarely develop the frank disease. *Bos taurus* breeds tend to be more susceptible than the *Bos indicus* breeds. Confirmation by detecting the parasite in blood smears is relatively easily achieved in infections with *B. bigemina* but usually only a low proportion of the red cells are

Fig. 2.5
The pale mucous membrane resulting from anaemia in a cow suffering from babesiosis. However, other conditions, including haemonchosis, fasciolosis and trypanosomosis might cause a similar condition.

infected with *B. bovis*. Serological diagnostic procedures, such as the indirect fluorescent antibody test (IFA) and enzyme-linked immuno-sorbent assay technique (ELISA) are now well established.

Animals which recover from the clinical disease are immune to reinfection but continue to carry the parasite (premunity) for up to 2 years. Control of the disease is therefore best achieved by facilitating a state of enzootic stability in which all the cattle are infected while they are calves and remain carriers due to continuous reinfection, but rarely develop clinical disease. However, if this situation is disturbed, by the introduction of uninfected stock or by over enthusiastic dipping regimes, enzootic instability ensues and susceptible animals succumb to the disease. Chemotherapy is effective and may be used prophylactically, while vaccination using blood containing a strain of parasites attenuated by repeated passage is widely practised, especially in Australia against *B. bovis*. Vaccination provides protection for up to 2 years and should always be considered when it is necessary to introduce uninfected animals into an area where babesiosis is endemic.

Theileria, on the other hand, spends the earlier part of the mammalian stages in its life cycle within mononuclear lymphoid cells rather than within erythrocytes. However, the infective form for the tick, the piroplasm, is found in the red blood cells. There are several species, including some such as *T. buffeli* (syn. *T. mutans*), which are of lesser pathogenicity. Those which are of major economic importance are *T. annulata* and *T. parva*, which infect cattle and, to a lesser extent, *T. hirci* which infects small ruminants. These species all use two- or three-host ticks as their intermediate hosts and are transmitted between most stages of the tick's life cycle, but not via the egg. *T. parva* is restricted to East and Central Africa, within the range of its vector *Rhipicephalus appendiculatus (q.v.)* but the other two species use the widely spread *Hyalomma* as their intermediate host and occur in North Africa and across tropical and subtropical Asia.

T. parva causes the disease called East Coast fever (ECF) in which the cattle exhibit a severe fever and swollen lymph glands. Various other signs may be shown, somewhat inconsistently, before death ensues in 1826 days. Mortality rates tend to be very high in susceptible animals. The signs associated with tropical theileriosis, the disease caused by *T. annulata*, are broadly similar but anaemia is a more consistent feature. Again mortality is high in acute cases but relatively chronic cases with protracted recovery also occur. In both cases, diagnosis is based on a combination of the clinical picture, the history and observation of the piroplasms in blood smears.

Coccidia

There are numerous species of coccidia in domestic livestock and many of these are found in the tropics, either exclusively or because they occur globally. Most coccidia have simple life cycles, with direct infection of their mammalian host. Development and multiplication within the intestinal mucosa lead on to the production of the characteristic small cysts, the oocysts, which are passed in large numbers in the faeces. The pathogenicity of the various species varies widely but some of them can cause serious disease, with acute bloody scouring and fatalities, especially in young animals. The two main genera are *Eimeria* and *Isospora* which have characteristically differing oocysts. The oocysts are not immediately infective when passed in the faeces and disease is best prevented by good hygiene, which involves separating the animals, and especially young stock, from their faeces using methods such as housing with slatted floors.

A number of other isosporan coccidia have complex life cycles, usually involving cats or sometimes dogs as their final hosts, but with the ability to multiply asexually within cysts set within the musculature of a wide range of other mammals and sometimes birds. One of these species, *Toxoplasma gondii*, causes abortion in sheep but is also zoonotic and can cause serious human disease, particularly if acquired during pregnancy. Another, the tropical parasite *Besnoitia besnoiti*, infects cattle and heavy infections of the intramuscular cysts can reduce the value of the meat. A parasite of goats, *B. caprae* which is similar to *B. besnoiti* but is not infectious for cattle, has recently been described in Kenya and Iran. The final host of this species is not known.

Arthropods

Parasitic arthropods include ticks, lice, fleas and some mites and flies. Many of these are ectoparasites in that they live on the surface of their hosts rather than within their bodies. Some are important as parasites in their own right but, especially in the tropics, many of them are more important because they are the vectors for a wide range of protozoal, helminth, rickettsial or viral pathogens.

Flies, fleas and lice are insects, while ticks and mites are acarines, related to spiders. However, each of these groups differs from the others sufficiently so that, for practical purposes, it is better to consider them separately.

Flies

This very large group of insects includes many which are non-parasitic. On the other hand, some have larvae which are parasitic within the bodies of mammals, while others are the vectors of major disease-causing organisms. Many others, including the large horseflies (*Tabanus*), deer flies (*Chrysops*) and clegs (*Haematopota*), the smaller stable flies (*Stomoxys*), and horn flies (*Haemotobia*), or the much smaller mosquitoes (e.g. *Aedes, Culex, Anopheles*, etc.), the midges (such as *Culicoides*), and the sandflies (such as *Simulium*), irritate livestock while taking blood meals. Many of these flies are vectors of pathogenic organisms, as are some of those, such as *Musca*, which do not actually take blood meals, feeding instead by a sponging action on mucous, but which may nevertheless irritate livestock by their mere presence.

Myiasis is caused by those flies which lay their eggs on livestock. Some of these are only facultative parasites in that their grubs can equally develop on rotting carcases. However, the blowflies such as the greenbottles, *Lucilia*, or the bluebottles, *Calliphora*, are attracted to wounds or to soiled areas around the hindquarters of sheep. They lay their eggs in such regions and the grubs which later hatch out may damage the skin or at least exacerbate the wounds in which they occur.

The grubs of some other flies, such as the nasal bots of sheep, *Oestrus*, and camels, *Cephalopina*, the screw worms, *Chrysoma* and *Cochliomyia*, the warble flies of cattle, *Hypoderma*, and the stomach bots of horses, *Gastrophilus*, are obligate parasites, migrating through their host's tissues to specific sites in the nose (*Oestrus ovis*), in the stomach (*Gastrophilus*) or under the skin, where they complete their development. Warble flies cause considerable damage to hides, while sheep and camels infected with large numbers of nasal bots may be debilitated or even die.

A particularly important genus in sub-Saharan Africa is *Glossina*, the blood-sucking tsetse flies, vectors of the protozoal trypanosomes which cause trypanosomosis (*q.v.*). These flies feed primarily on wild animals that form the natural mammalian hosts of the trypanosomes. They are true intermediate hosts in which *Trypanosoma brucei, T. congolense, T. simiae* and *T. vivax* undergo development.

Although flying insects are usually susceptible to most common insecticides, their mobility makes them hard to control in this way and they are usually better controlled by reducing or eliminating the number of environments in which they breed. Hence, the optimum method of control varies with the biology of the insect. Thus, while reducing the areas of stagnant water in a locality will help to control the prevalence of mosquitoes, controlling stable and house flies necessitates reducing the amount of manure and household refuse in the local environment. An increased density of human habitation tends to reduce the prevalence of tsetse flies or even to eliminate them locally. Other methods of reducing the prevalence of tsetse flies in order to control trypanosomosis are considered earlier under the heading 'Trypanosomes'. Topical insecticides may be effective in cases of myiasis. Systemic insecticides, such as ivermectin, are effective against migrating larvae, but the local reactions around dying grubs may be harmful.

Lice

These are wingless ectoparasitic insects which are always to be found infesting the skin of their hosts. They occur worldwide but are particularly prevalent in warm climates. Sucking lice, such as *Haematopinus*, which occur on pigs, cattle and buffaloes, or *Linognathus*, which are found on cattle, sheep and goats, have elongated heads bearing specialized mouth parts with which they can pierce the skin of their host, suck blood and so may cause anaemia and serious cutaneous damage. Sucking lice are only parasitic on mammals, but most species of biting lice are parasitic on poultry. Biting lice have broad heads and mouth parts, with which they can abrade the surface of the epidermis. They are generally less pathogenic than sucking lice, although heavy infestations with *Damalinia* can cause debility and damage to cattle hides.

Lice are dorso-ventrally flattened and are around 25 mm in length, with legs which are adapted for grasping the hairs or feathers of their hosts. They lay their eggs on the host and, as they are incapable of surviving off their correct hosts for any length of time, are relatively easy to control by topical applications of insecticides. However, they are also prone to develop resistance to the insecticides which are in common use.

Fleas.

Like lice, these are wingless ectoparasitic insects and they are also blood-suckers. However, in contrast to lice, they are laterally flattened and have powerful legs that facilitate their movement onto and off the hosts. Unlike lice, fleas lay their eggs off the host and, with the exception of the chigger flea, *Tunga*, a common parasite of pigs and humans in the tropics, they may spend most of their lives off their hosts. Fleas are much less host-specific than lice and even those whose main hosts are animals, including poultry, will also attack humans. Except for *Tunga*, most species of fleas only infest their hosts when they require a blood meal, but heavy infestations can cause great irritation and sometimes severe anaemia, especially in young animals. Fleas are usually susceptible to common insecticides but

merely treating the host will not control them because, at any one time, most individuals, including all the larvae, are not on the host but in its environment.

Mites

Parasitic mites cause the skin disease called mange. All stages of these microscopic acarines live and multiply on the same host. The burrowing mites, *Sarcoptes* and *Notoedres*, live within the dermal layers, whereas *Psoroptes* and *Chorioptes* live on the surface of the skin. However, both kinds can cause great irritation and debility.

The severe pruritus associated with mange caused by *Sarcoptes* is a particular problem in pigs and camels but may occur on other livestock. In contrast, the small, rather elongated mite *Demodex*, which lives within the hair follicles, will also infest most domestic mammals, but usually causes only thickening of the skin, with little or no irritation, although a harmful secondary bacterial infection may ensue, especially in dogs.

Of the non-burrowing mites, *Psoroptes* mainly affects sheep causing the disease called sheep scab, while *Chorioptes* mainly affects cattle. However, both of these can infest either host and can also be found on other livestock. Heavy infections with these mites will cause widespread exudative inflammation and scab formation.

Non-burrowing mites can be effectively treated by topical application of insecticides but the burrowing mites are better treated by the use of a systemic insecticide, such as ivermectin.

A group of non-parasitic mites, the oribatid mites, which are free-living and occur on herbage, are the intermediate hosts of anoplocephalid (*q.v*.) tapeworms of ruminants.

Ticks

Ticks are very important ectoparasites, particularly in the tropics, where they transmit the pathogens which cause some of the most serious diseases of domestic livestock. Most of the important species are hard ticks, which have a chitinous protective shield (the scutum) on their backs. This is larger in the males than in the females and may carry various patterns or decorations which are of value in identifying the tick. The so-called soft ticks do not have the hard scutum, but they are tough and leathery and are able to withstand long periods of hot, dry conditions without feeding.

Large numbers of hard ticks can themselves cause serious disease, including anaemia and tick paralysis and sweating sickness in young cattle. These latter two diseases result from excessive amounts of toxins being injected into the hosts when large numbers of ticks are feeding. Smaller numbers of ticks can cause debility, loss of productivity and cutaneous damage. The large 'bont' tick, *Amblyomma*, has been shown to cause an immunodeficiency, which may result in a severe skin disease of cattle (dermatophilosis or streptothricosis), which is directly caused by infection with *Dermatophilus congolensis*, an otherwise ubiquitous commensal of low pathogenicity.

All ticks are parasitic as each stage requires a blood meal in order to continue its development. In the course of its blood meal, the body of the adult female tick swells dramatically, the engorged tick finally dropping off the host and laying her eggs on the ground. The larvae which hatch out of the eggs then seek a suitable host.

The one-host ticks, such as *Boophilus* spp., remain on the same host throughout their development from larvae through nymph to adult, which takes about 3 weeks. Two-host ticks, such as *Rhipicephalus evertsi*, use different hosts for the adult and the two immature stages. For the latter they may use small rodents and similar animals for their hosts, so that less time is spent on the final host. The three-host ticks, such as most species of *Hyalomma, Amblyomma* (Fig. 2.6) and *Rhipicephalus*, including *R. appendiculatus*, the vector of East Coast fever (*q.v*.), normally use a different host for each stage, spending relatively little time on each host. All ticks pass most of their lives on the pasture or secreted in holes in walls, rather than on their hosts, but three-host ticks tend to be particularly resistant to adverse conditions and are able to survive for long periods on the pasture. In

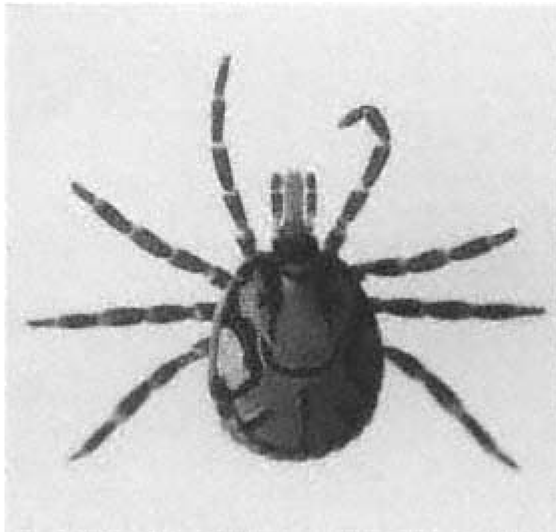

Fig. 2.6
A male *Amblyomma hebraeum* tick. This species is the vector of *Cowdria ruminatium*, the rickettsial organism which is the cause of heartwater in cattle in Southern Africa.

tropical countries, where the temperatures are consistently warm enough for the ticks to remain active throughout the year, their reproductive activity occurs mainly during the rainy season.

Some species of soft ticks are also important tropical parasites and vectors of disease. They tend to inhabit the burrows or beds of their hosts, and have repeated immature stages, each of which takes a short blood meal before developing further. *Argas* are parasites of poultry while *Ornithodorus* are parasites of mammals, notably of pigs (*O. moubata* is the vector of African swine fever virus) and *Otobius* are found in the ears of cattle and other mammals throughout the tropics. All the common species of soft ticks may also feed on humans.

For many years the control of hard ticks in cattle has been based almost exclusively on the regular topical application of insecticides, such as organophosphates, synthetic pyrethroids or amitraz. These were usually applied by driving the animals through dip tanks or by spraying. The latter may be conducted by hand spraying individual animals or the cattle may be driven through a spray-race. However, problems associated with the ticks becoming resistant to the widely used and more effective insecticides have become commonplace and it has also been shown that there is little benefit to be gained from giving such prophylactic treatments to indigenous breeds, especially native zebu cattle. Conversely, consistent prophylactic use of insecticides may be essential to the survival of high-value exotic animals in areas where ticks, and the diseases for which they act as vectors, are prevalent. The need to maintain tick control procedures may totally outweigh the advantages of keeping exotic animals, especially if local political or financial instability is likely to render the necessary consistency of treatment unattainable.

Vertebrate hosts subjected to repeated infestation by ticks develop a degree of resistance. A commercial recombinant vaccine has recently been developed against *Boophilus microplus*. Such vaccines may offer the possibility of improved control without causing the environmental damage associated with the widespread use of chemical insecticides.

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3
Nutrition and Feeding

Introduction

One of the ultimate objectives of any livestock industry is the conversion into animal products of feeds which are either inedible by man or surplus to his immediate requirements.

In a world where the ever-increasing human population exercises continual and probably mounting pressure on world feed resources it is inevitable that conventional animal feeds should become increasingly more expensive. This is leading to a search for new, often unconventional feeds, and for effective methods of processing presently inedible roughages into more nutritious feeds. Such handicaps for the animal feeders are reinforced by the fact that the production of animal products inevitably includes a double conversion of basic food constituents. First, soil nutrients are converted into plant products. The latter are then fed to animals for conversion into animal products. One example of this double conversion is that the average efficiency of conversion of fertilizer nitrogen into plant protein is approximately 50%, while the average efficiencies of conversion of plant into animal protein in the temperate zone are approximately 40, 1825, 24, 19 and 11% for milk, eggs, poultry meat, pork and beef, respectively (Table 3.1). For a variety of reasons conversion in the tropics is even less efficient. For example Cuthbertson (1969) has stated that the average efficiency of conversion of plant to animal protein during milk production in the tropics is only 25%. While it may be argued that research during the years ahead will undoubtedly discover new methods of increasing the efficiency of nitrogen conversion, it has to be accepted that two steps in the conversion of nitrogen fertilizer into edible protein can never be as efficient as one. This means that it will always be possible to feed more humans per unit of cultivable land by growing crops for direct human consumption than by growing crops for conversion by domestic livestock into edible animal products.

What then are the justifications for raising any livestock? First, most humans demand a mixed diet as man is an omnivorous species and the majority are willing to pay higher prices for foods of animal origin than they are for foods of plant origin. Nutritionally, it may be possible for man to exist solely on plant foods, but less total bulk is required of a good mixed diet than of one containing only foods of plant origin. In addition, foods of animal origin are very palatable and usually possess a high protein, fat and mineral content. Secondly, there are many plant foods, particularly forages, that cannot be properly digested by man and that at present can only be processed into foods suitable for man by the feeding of them to livestock. Thirdly, in ecologically stable agricultural systems, plants and animals are complementary, and the utilization of both as sources of food may increase total food production per unit area of available land.

In the past all animal feeds were derived from three sources. These were: crops other than forage, the by-products of crop and animal processing, and natural or planted forage. Today there is a fourth possible source that may increase in importance: synthesis from non-biological

Table 3.1 Approximate efficiency of some domestic livestock in converting the energy and protein of animal feeds into food for man. (*Source*: Cuthbertson. 1969.)

Type of animal	Efficiency of conversion (%)	
	Energy	Protein
Cattle		
Milk production during lactation	27	40
Beef production during fattening	11	11
Pigs		
Pork production	27	19
Poultry		
Broiler production	7	24
Egg production	1317	1825

The data have been calculated for temperate-zone countries and not specifically for the tropics.

materials, for example urea from nitrogen or protein concentrate from oil or natural gas.

Most feeds for livestock may be conveniently classified into two major types: roughage and concentrates. Roughages are characterized by the relatively large amounts of crude fibre that their dry matter contains. As a group they can be further subdivided and classified into dry roughages and succulents, the latter containing large quantities of water. Major sources of roughage in the tropics are range pastures, bush and tree forage and crop residues; particularly cereal straws. Domestic ruminants such as buffaloes, cattle, sheep, goats, camels and llamoids differ from non-ruminants in possessing a complex digestive tract capable of utilizing large quantities of roughage feeds, whilst herbivores such as the horse and the donkey, though not ruminants, possess an enlarged caecum and colon that also assists in the digestion of these feeds.

In general, concentrate feeds contain less crude fibre than roughages and relatively large but varying quantities of carbohydrates, crude protein and fat, together with relatively little water. They can be utilized by non-ruminant livestock such as pigs and poultry as well as by ruminants. In addition there are a limited number of feeds that are difficult to classify into either category.

A knowledge of the chemical components of different feeds and of the basic principles of feeding are essential for successful livestock production. The fundamental principles of nutrition are universally applicable, but all aspects of the nutrition of livestock in tropical climates are not yet fully understood. This chapter will include details of the components of food, the evaluation of livestock feeds and limited data on the types of feed available in the tropics. The nutritional requirements of, and feeding standards for, different species and classes of domestic livestock are not discussed, but will be considered for each species in specific chapters in Part II.

Food Components

The food that an animal eats is essentially composed of the same elements that form its body and products. The total amount and the relative proportions of the elements in each food vary greatly, but they are integrated to form compounds or groups of similar substances upon which a classification of food ingredients can be based. Thus, all foods contain water and their dry matter consists of minerals and organic matter. The latter includes three major groups of substances: nitrogenous compounds, carbohydrates and lipids, together with a quantitatively small but qualitatively important group of organic accessory foods known as vitamins.

A simple classification of these food constituents gives no indication of their relative importance, either quantitatively or qualitatively. Each must be considered with reference to its function within the animal's body and in relation to each other. Therefore, each will be discussed separately.

Water

Water is more vital for the maintenance of the animal's life than any other food component. It is the main constituent of all body fluids, being essential for the transport of nutrients to body tissues and the excretion of waste products through the urine and faeces. It is also vital for the proper functioning of most enzymic reactions as these take place in solution and involve hydrolysis.

In addition body water plays an all important role in the animal's thermoregulatory mechanisms. Evaporation of water from lung and skin surfaces helps the animal to dispose of unwanted heat and the high specific heat of the body water assists the animal to accommodate itself to large changes in heat production with little change in body temperature.

The water content of the animal's body varies with age. Newborn animals consist of 7580% water, whereas mature, fat animals may contain only 50% or less. The average animal probably consists of between 55 and 65% water.

Water requirement increases with growth, with an increase in productive processes such as lactation and egg laying and with increased physical exercise as when animals are worked and when the animal is subject to heat stress. Requirements vary between different species, between breeds or varieties within species and between individuals within breeds. In fact, water requirement appears to be a very individual and specific characteristic. For example, Payne (1965) found that the range in the water intake of growing, indigenous zebu cattle managed in a semi-arid environment in East Africa was 343 litres/day. Average water requirements of some ruminant livestock in the semi-arid tropics are shown in Table 3.2. This data should only be used as an approximate guide. Average intake is reduced when livestock are water deprived.

Water intoxication can occur following the ingestion of excessive quantities. However, the condition is uncommon in practice. Livestock owners in the semi-arid tropics are usually skilled in their watering techniques and the livestock have developed physiological mechanisms for coping with large water intakes, perhaps by retaining a large quantity of water in the rumen until the osmolality has been raised in some manner (King, 1983).

Animals acquire water in three ways. Mainly by drinking free water, but also by utilizing the water that forms part of the food that they consume, and occasionally by manufacturing small quantities of metabolic water obtained by the oxidation of fat within their own body.

Some wild animals, particularly those whose habitat is the desert or desert fringe, appear to be able to survive without access to free water. They presumably manage on dew, on the small amount of water available in the dry vegetation that they consume and perhaps to a very limited extent on metabolic water. All domestic animals ultimately require access to free water, some daily and some at less frequent intervals. The camel is the outstanding example of a domestic animal which can withstand infrequent watering intervals. An interesting example as to how domestic livestock can thrive on the water available in the vegetation, without access to free water, occurs in the desert of northwest Sudan. After a

Table 3.2 Some estimates of the water requirements of ruminant livestock in the semi-arid tropics. (*Sources*: aGuideline for development by King (1983) and bmodifications of data from Baudelaire (1972).)

Type of livestock	Average liveweight (kg)	Average requirementa (litres/day)	Dry season requirementb (litres/day)	Dry season interval between drinks (days)
Camels	500	30	5575	45 or longer
Zebu cattle	350	25	3040	13
Sheep	35	5	45	12
Goats	30	5	45	12

specific set of climatic conditions that do not necessarily occur annually, the pastoralists are able to graze their camels and sheep for quite long periods across considerable tracts of waterless country. This is because the ephemeral vegetation that occurs, known in the Sudan as the *gizzu*, contains sufficient water to satisfy the normal needs of the livestock.

As stated previously, different species of domestic animals differ in their water requirements and these differences are reflected in their respective abilities to withstand dehydration and in their demand for free water. The camel has an exceptional tolerance of heat and water deprivation (see Chapter 11), can withstand the loss of up to 27% of its body weight and is able to drink exceptional quantities of water at any one time (Schmidt-Nielsen, 1964). Some breeds of sheep also possess an exceptional tolerance of dehydration (Schmidt-Nielsen, 1964) and it is likely that many breeds of goats are also very tolerant of partial dehydration. Cattle are not generally as tolerant as camels and sheep, but their requirements for free water vary with type; *Bos indicus* breeds requiring less water than most *B. taurus* breeds when managed in the same environment (French, 1956). However, the N'Dama, an indigenous *B. taurus* breed from West Africa, is likely to be as tolerant of dehydration as any *B. indicus* breed. Payne (1965) reported that acclimatized East African *B. indicus*-type cattle can lose up to 17% of their body weight between drinking, without apparent harm. Buffaloes and pigs are relatively intolerant of water deprivation.

In the humid tropics the grazing animal's demand for water may be largely satisfied by the high water content of the forage and by the free water remaining on it after rainfall. Indeed, the animal's intake of high-water-content forage may make for difficulties in it obtaining a sufficiently high dry matter intake. Nevertheless, daily access to free water is always desirable. All yarded or housed animals in the wet tropics must have access to free water, preferably throughout the 24 hours.

In the dry tropics, the direct and indirect effects of low rainfall are additive in their effect on grazing animals during the dry season. The decreasing water content of the available forage increases the animal's demand for water at a time when surface water resources are diminishing and the animal has to walk further to obtain both feed and water. Additional walking raises food and water demand, as increased muscular activity requires additional feed and generates additional heat that has to be dissipated, further depleting the animal's water resources. At the same time ambient day temperatures rise during the dry season, with a consequent further increase in the animal's water requirements. In practice this means that often in the arid or semiarid tropics livestock are watered only every second or third day. If adequate feed is available this reduces productivity, but experimental work in East Africa (Payne, 1965) has shown that if inadequate feed is available water deprivation, if not too prolonged, can be advantageous to the animal, as it assists in the conservation of nitrogen and possibly of other food constituents in its body.

Water deprivation also conserves water if the latter is in short supply. In the East African experiments referred to above, water deprivation for 48 and 72 hours reduced total water intake by 10 and 26%, respectively. Withholding water from sheep also appears to have the same sparing effect on total water consumption.

Animals living in the dry tropics are also subject to another hazard. In many regions the mineral content of the only free water available progressively rises as the dry season advances and may become so concentrated as to be unsuitable for drinking. Details of the average tolerance of different livestock species to salty drinking water are provided in Table 3.3. Camels, cattle, sheep and goats can to some extent acclimatize themselves to such conditions and become comparatively tolerant of highly mineralized water. For example, Denton *et al*. (1961) stated that livestock adapt to highly mineralized water and that in certain regions in Australia cattle and sheep are known to thrive on water containing 1.5% and 1.9% minerals, respectively.

It would be expected that the consumption of

Table 3.3 Tolerance of salty drinking water by domestic livestock. (*Source*: King, 1983.)

Species	% total salts in water
Camels	5.5
Goats	1.5
Sheep	1.32.0
Zebu cattle	1.01.5
Donkeys	1.0
Horses	0.9
Pigs	0.9

highly mineralized water might have a considerable effect on the mineral metabolism of animals. This appears to be the case. For example, French (1956) reported that the consumption of alkaline water (0.37% sodium carbonate) in the dry regions of East Africa increased sodium and chlorine retention but reduced the retention of calcium, potassium, magnesium and phosphorus.

When water is freely available, housed or yarded animals usually drink at frequent, short intervals, imbibing a small quantity at any one time. Grazing animals tend to drink in the cool of the morning or in the evening if they have a free choice, but usually they are watered only once every 24 hours. Often this single watering takes place during the heat of the middle of the day as the animals are grazed to the watering place, watered and then grazed away from the watering place.

The temperature of drinking water is of some importance, cool water being preferable to warm, as drinking cool water assists the thermoregulatory mechanisms of the animal to dissipate body heat.

Nitrogenous Compounds

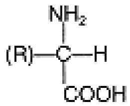
The nitrogenous compounds in a feed include the proteins and the non-protein nitrogenous compounds. The latter include amino acids, amines, amides, nitrates and alkaloids, etc. Nitrogenous substances in a feed are usually expressed in terms of crude protein (CP) content.

Proteins.

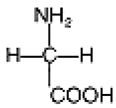
Proteins are complex organic compounds of high molecular weight with many and diverse functions within the animal's body. They are found in all living cells where they participate in all phases of cell activity. They also serve as structural elements in all soft body tissue. All known enzymes, many hormones, the oxygen-carrying pigment of the blood, collagen, antibodies and the chemical units of hereditary transmission are all proteins. They consist of chains of amino acids. Most of these are characterized by having a carboxyl group (-COOH) and an amino group (-NH2) attached to the same carbon atom (Fig. 3.1). Also attached to the carbon atom at the position (R) in Fig. 3.1 is the remainder of the amino acid molecule which will of course vary in composition. Approximately 100 amino acids have been isolated from biological materials, but only 25 of these are generally considered to be components of proteins. There is, therefore a great variety of proteins, the characteristics of each depending upon the number and the type of amino acids composing their molecule.

Plants and many microorganisms are able to synthesize proteins from simple nitrogenous

Amino acids are characterized by the possession of a basic nitrogenous group (NH2) and an acidic carboxyl group (COOH) as show below

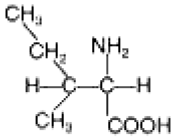


The nature of the (R) group varies with the amino acid.It may be an hydrogen atom as in glycine:



glycine

or a more complex group as in isoleucine:



isoleucine

Fig. 3.1
The amino acid molecule.

compounds such as nitrates. Non-ruminant animals must have a dietary supply of amino acids. They are, however, able to synthesize some that they require. Those that they cannot synthesize are known as essential amino acids. Using the rat as an experimental, non-ruminant animal, it is at present recognized that growing, non-ruminant animals apparently require to ingest 10 essential amino acids. These are:

arginine	methionine
histidine	phenylalanine
isoleucine	threonine
leucine	tryptophan
lysine	valine

Arginine and histidine may not be essential in the adult non-ruminant animal. Birds require, in addition, glycine.

Ruminant animals possess biological systems that can synthesize all the amino acids that they require within their digestive tract. The bacteria and protozoa in the tract synthesize amino acids (including the essential ones) from dietary protein and non-protein nitrogen. The microbial protein so produced is later digested by the animal at a lower point in the digestive tract with the production of the amino acids required by the animal for its own protein synthesis, but not necessarily in sufficient quantity for a high level of production.

Naturally, those proteins in the ingested food whose amino acid composition most closely resembles that of the amino acid composition of the required body protein possess a superior feeding value or a higher protein quality. Food proteins derived from the animal's body, such as the protein in blood meal, can be broken down and synthesized into required body proteins with less waste than the protein of a grain such as sorghum. Blood meal protein is therefore said to possess a higher *biological value* (BV) than sorghum grain protein. The biological value of a protein can therefore be used as an assessment of the relative values of different proteins for non-ruminant animals (Table 3.4). Protein feeds of animal origin usually possess a higher biological value than those of plant origin.

Table 3.4 The biological value of the protein in selected feeds used in pig feeding. (*Source*: Armstrong & Mitchell, 1955.)

Feed	Biological value of the protein
Milk	9597
Fish meal	7489
Soybean meal	6376
Cottonseed meal	63
Maize	4961

Deficiency of an essential amino acid in the diet of non-ruminants may lead to a failure of growth and eventual death. Different non-ruminants have different requirements for the essential amino acids. In birds glycine cannot be synthesized sufficiently rapidly for adequate feathering since the protein keratin, required for feathering, contains a high proportion of glycine. Lysine, methionine, threonine and tryptophan, in that order, are the amino acids most likely to limit growth and reproduction in the majority of non-ruminants. Their deficiency can be made good by adding them individually to the feed. Thus plant protein diets of low biological value can be supplemented with individual amino acids and their biological value improved to equal that of protein of animal origin. This supplementation technique is now widely used in the manufacture of feeds for pigs and poultry.

Non-Protein Nitrogenous Compounds

A considerable variety of nitrogenous compounds which cannot be classified as proteins occur in both plants and animals. These include alkaloids, amides, amines, amino acids, nitrates, nitrogenous lipids, purines, pyrimidines and some compounds in the vitamin B complex. In this general text only the briefest mention can be made of some of these. For further information readers should consult McDonald *et al*. (1995).

Amines

These are often produced from amino acidswhich comprise the major part of the non-protein nitrogen fractionby microorganisms. Many thus occur as decomposition end-products and possess toxic properties.

Amides

A major amide is urea, the main end-product of nitrogen metabolism in mammals.

Nitrates

Large amounts of nitrates are often found in forage that has been heavily fertilized. Nitrates may be reduced in the rumen to nitrites possessing toxic properties.

Alkaloids

These occur in specific plants and are of practical interest as many of them possess toxic properties. Well-known examples of toxic or semi-toxic alkaloids in tropical plants are the occurrence of ricinine in *Ricinus communis* (castor) and mimosine in *Lucaena leucocephala*. Other plants contain valuable drugs; for example morphine is obtained from the latex of the opium poppy (*Papaver somniferum*) and cocaine from the leaves of the coca plant (*Erythroxylon coca*).

Protein Requirements

While the amino acid content of the protein in the ration is important for non-ruminants and for the pre-rumination period of young ruminants it is of less importance in older ruminants. What is of major importance is the total nitrogenous content and whether there is a balance with other nutrients in the ration (Preston, 1995).

The total nitrogen (N) content of a feed is analysed using a modified Kjeldahl method and the crude protein (CP) content calculated using the formula:

$$CP(g/kg) = gN/kg \times 6.25$$

Two assumptions are made in using this formula. First that all the nitrogen in the feed is present as protein and secondly that all food proteins contain the same amount of nitrogen. Neither assumption is tenable. Nevertheless, the use of CP and total digestible crude protein (DCP) values to express the protein requirement of all except very young ruminants is convenient and is commonly used. In feeding practice the quality of the proteins fed to ruminants should not be entirely ignored. It is usually economic to feed a variety of protein concentrates as the pooling of proteins containing different types and quantities of the various amino acids improves the ability of the microbial population in the gut of the ruminant to synthesize rapidly all the amino acids required.

In the case of non-ruminant animals requirement can be expressed in terms of DCP with the stipulation that the nitrogenous content of the ration should contain *x* per cent lysine, *y* per cent methionine, etc. The difficulty of this methodology is that the need for any particular amino acid, expressed as a percentage of the total nitrogen ingested, may change with the rate and stage of growth of the animal and with the breed.

Calculation of minimal protein requirements involves:

(1) Assessment of nitrogen retention within the body for growth and other productive purposes and for maintenance (NR).

(2) Assessment of endogenous urinary nitrogen and metabolic faecal nitrogen losses (NE).

The sum of these, i.e. (NR + NE), is multiplied by 6.25 to provide the minimal protein requirement, i.e. 6.25 (NR + NE). If this figure is divided by the average biological value expressed as a decimal an estimate is obtained of the 'true' DCP requirement.

As almost all living cells are composed of protein and the cells are continuously undergoing degeneration and disintegration, a continuous supply of new protein is required by the body even when it is at rest. Thus every animal must receive a continuous though limited supply of protein if it is to maintain its health and not lose weight and condition. In addition any increase in productivity, with the exception of an increase in work, greatly increases the demand for dietary protein.

Excess protein in the diet will be 'deaminated' in the digestive tract, the excess nitrogen being excreted in the urine and the faeces. The energy component of the protein can then be used by the animal in the normal metabolic manner. This is, of course, a wasteful process as protein concentrate feeds are usually more expensive to purchase than energy concentrate feeds. In addition, the ingestion of excessive quantities of protein may disturb, to some extent, the normal working of the digestive system.

It is, however, usually desirable to feed rather more protein than the minimal requirements as protein usually improves the palatability of feeds and may thus increase total feed intake. In addition protein is associated with desirable minerals and/or vitamins in many feeds.

The specific protein requirements of the different types of livestock are further discussed in the various chapters in Part II concerned with each type of livestock.

Carbohydrates

Carbohydrates in feeds can be divided into two groups: sugars and non-sugars.

Sugars

The simple sugars, termed monosaccharides, are easily digested by non-ruminant animals. They include ribose (general formula $C_5H_{10}O_5$) and glucose and fructose ($C_6H_{12}O_6$). Disaccharides, such as sucrose (cane sugar), maltose and lactose (milk sugar) possess the general formula $C_{12}H_{22}O_{11}$. Under normal circumstances disaccharides are also readily digested, being broken down in the digestive tract to monosaccharides.

Non-Sugar or Polysaccharides.

There are a large number of different types of polysaccharide, but all possess high molecular weights and have to be broken down into simple sugars before they can be utilized by non-ruminant animals. Some, such as the starches, occur as reserve food in plants, others such as the celluloses are the structural materials of plant cells. Glycogen is of importance as a major storage material in animal bodies. Other major polysaccharides are the hemicelluloses that include the exudate gums such as gum arabic obtained from *Acacia senegal* and other *Acacia* spp.

Lignin

This is a collective term for a group of closely related compounds that are not carbohydrates but are intimately linked to celluloses and hemicelluloses in secondary cell walls. These compounds are highly resistant to chemical and enzymic degradation and are not appreciably broken down by the microbia in the ruminant digestive tract. As they are so closely linked to the carbohydrates in the cell walls of plants they exert a major effect on the digestibility of plant feeds. In addition, in tropical climates, the process of lignification in plants appears to commence at an earlier age than it normally would in temperate climates. Thus forages in the tropics are often appreciably less digestible than similar forages of the same age in temperate climates.

Non-ruminant livestock cannot efficiently digest many of the non-sugars. In ruminants, however, celluloses and other polysaccharides are broken down by bacteria and protozoa in the digestive tract. The products are not simple sugars but volatile fatty acids (VFAs), mainly acetic, proprionic and butyric acids together with methane. The VFAs are used by the ruminant animal via various metabolic pathways for maintenance energy and for the synthesis of body and milk fat. Acetic acid is of paramount importance in the synthesis of milk fat. Thus the percentage of fat in milk depends to some extent on the quantity of acetic acid that is produced in the digestive tract and this depends in turn on the composition of the diet. For example, dairy cows fed on diets with a low roughage content, tend to produce milk with a low butterfat content.

Carbohydrates form the largest constituent of

plants and are therefore the major part of the food of domestic livestock. However, very little carbohydrate is found in the animal's body. The reason for this is that after digestion and absorption carbohydrates are either oxidized directly for the production of energy or they are transferred and stored in the form of fat.

Cereals, tubers and roots are the feeds that are richest in sugars and starches, whereas forages, particularly straws, contain less sugar and starch and very large quantities of fibre.

Although crude fibre cannot normally be easily digested, even by ruminant livestock, a certain amount is required in the diet of all animals after they have been weaned. Ruminants require more than non-ruminants. However, even the pig requires some fibre in its diet. In moderate quantities fibre ensures the proper working of the digestive system and gives a feeling of repletion which is one essential for proper feeding. However, as it is the cheapest feed and is usually in such plentiful supply the tendency is to always feed too much. When this occurs the digestion of all food constituents is depressed and the sheer bulk involved may depress total intake below nutritional needs. This often happens when cattle graze old, dead forage at the end of the dry season or when pigs are fed only rice bran.

There are major differences between ruminant species in their ability to utilize roughages. For example, buffaloes are known to thrive on forage that will not support cattle, while camels, llamoids, tropical breeds of sheep and goats all appear to be able to utilize roughages rather more efficiently than cattle. The reasons for this are not, as yet, well understood.

If a sufficiency of carbohydrate food is not available the animal can use excess dietary protein, or if neither is available it can utilize its own fat reserves, as a source of energy.

Lipids

Lipids are insoluble in water but soluble in common organic solvents. They include: fats and oils; glycolipids that are found in grasses and legumes; phospholipids, constituents of many biological membranes; cerebrosides found in nerve tissues; waxes; steroids that include the bile acids, adrenal hormones and the sex hormonesoestrogen, androgens and progesterone; terpenes that include the essential oils such as lemon or camphor; and prostaglandins.

Fats and oils are the most important lipids from a dietary point of view as they are a major source of stored energy in plants and animals. They also act as carriers for vitamins A, D, E and K. At least three fatty acids are essential for most domestic mammals. These are linoleic, linolenic and arachidonic acids. Dietary linoleic acid is converted by mammals into arachidonic acid. When fats are estimated in feeds not only the true fats but many other lipids are extracted and included in the fat estimate.

In non-ruminants absorption of fats or glycerides takes place in the upper section of the small intestine. If the gut is full of dietary fat some may be absorbed in particulate form. Normally, however, triglycerides are transformed into monoglycerides and fatty acids through the agency of the enzyme lipase. Bile salts then mix with the monoglycerides and fatty acids to form completely dispersed micelles. These are absorbed by the mucosal cells of the digestive tract, the bile salts being returned to the lumen of the tract and the monoglycerides and fatty acids being resynthesized into triglycerides. In ruminants lysolecithin may take the place of the bile salts as no monoglycerides reach the small intestine and bile salts do not form micelles with free fatty acids.

The resynthesized triglycerides are utilized directly or they are stored in the fat deposits of the body. As triglycerides are a combination of different fatty acids and glycerol, different species of animals may possess different and specific types of body fat.

Fat is deposited everywhere in the body, either as a protective or as a supporting material. A considerable part of the body fat forms a subcutaneous layer which is usually more conspicuous in temperate-type than in tropical-type livestock. Ledger (1959) has shown, for example, that in East Africa *Bos taurus* and *B. indicus* cattle exhibit different patterns of fat deposition. At any particular degree of fatness *B. indicus* cattle

deposit more fat intramuscularly than subcutaneously compared with *B. taurus* cattle. This is presumably because subcutaneous fat deposits form an insulating layer that creates a barrier to heat flow from the deep body tissues to the skin, thus increasing heat stress. It has also been reported from South America that criollo-type cattle, which have been acclimatized to a tropical climate for several hundred years, deposit their subcutaneous fat in 'blobs' and not as a continuous layer. This also would facilitate transfer of heat from the deep body tissues to the outer skin of cattle. Other types of tropical livestock also deposit surplus fat at specific body sitescamels and zebu cattle in their humps and fat-tailed and fat-rumped sheep in their tails or rumps. In the past it has been suggested that these fat deposits were useful in times of water shortage as the animal could oxidize the fat in order to obtain metabolic water. A simple calculation, however, will demonstrate that the quantity of water thus obtained would be very small. It is more likely that the deposition of fat reserves at specific sites, rather than subcutaneously, is a device that primarily assists the animal to rid itself more easily of surplus heat.

The deposition of fat usually increases with age, and in quick-maturing animals the final deposition takes place between and around the muscle fibres. This process is known as marbling and has considerable commercial importance as it is associated with tenderness in meat. With present methods of husbandry, marbling is not as common in tropical as in temperate breeds of cattle.

As stated above, different species of livestock possess different and specific types of fat, and both the quantity and the type of fat are influenced by feeding. The quantity of fat that may be stored by the animal depends upon the total quantity of feed that it consumes rather than on how much fat there is in the food. Herbivores normally eat little fat, unless they are fed on oilcake, as forage usually contains only quite small quantities. Young animals can consume more fat than older animals and the milk consumed by all young mammals often contains considerable quantities of fat. Some breeds of buffalo, for example, secrete milk that contains as much as 14% fat. Young pigs can consume milk substitutes containing as much as 25% lard. The quality of fat as expressed in terms of hardness can be very easily influenced by feeding. For example, pigs fed large quantities of rice bran exhibit very soft fat, while those fed large quantities of cassava possess very hard fat.

The fat of different species may differ considerably in colour. Species and breeds of animals that convert the food pigments as soon as they are assimilated normally possess white fat, while those that do not rapidly convert the pigments may accumulate them in their fat deposits. For example, buffalo fat is white while the butterfat and body fat of certain breeds of cattle, such as the Jersey, are yellow.

Some fat, including the essential fatty acids, must be directly consumed by the animal as a deficiency adversely affects carbohydrate metabolism and increases the demand for certain B complex vitamins. Fats are also, as previously mentioned, the source of the fat-soluble A, D and E vitamins. In omnivorous animals fat also retards the emptying of the stomach and delays the onset of the feeling of hunger and restlessness associated with an empty stomach.

Minerals

The inclusion in the diet of a number of mineral elements that possess important metabolic roles is essential. If one or more of these elements are deficient in the diet, animals will ultimately exhibit clinical symptoms of deficiency.

Essential mineral elements may be classified into two groups (Table 3.5). Firstly, there are the macroelements: calcium, phosphorus, potassium, sodium, chlorine, sulphur and magnesium which are required by animals in relatively large quantities. Secondly, there are the trace or microelements which are required by animals only in very small quantities. At the present time the elements iron, copper, cobalt, iodine, manganese, zinc, molybdenum and selenium may be included in this group with certainty. In addition the elements arsenic, chromium, fluorine, nickel, silicon, tin and vanadium are also possibly essential for some, if not all, domestic livestock. McDowell (1997) has suggested that there is

Table 3.5 Essential mineral elements and their approximate concentrations in animal bodies. (*Sources*: McDonald *et al*., 1988 and McDowell, 1997.)

Essential				Possibly essential
Macroelements	(%)	Microelements	(ppm)	Microelements
Calcium	1.50	Cobalt	0.020.1	Arsenic
Chlorine	0.11	Copper	15	Boron
Magnesium	0.04	Iodine	0.30.6	Chromium
Phosphorus	1.00	Iron	2080	Fluorine
Potassium	0.20	Manganese	0.20.5	Nickel
Sodium	0.16	Molybdenum	14	Silicon
Sulphur	0.15	Selenium	12	Tin
		Zinc	1050	Vanadium

evidence that the elements boron, cadmium, lead and lithuanium are also in some manner essential.

The total amount of minerals in the animal's body is a very small proportion of the total body weight and the major part are found in the skeletal tissue. Nevertheless, small quantities of minerals are found in all parts of the body.

A short account of the metabolic role of each of these essential minerals is given below and in Tables 3.6 and 3.7. The various mineral deficiency symptoms encountered, some feed sources of the minerals and cures for specific deficiencies are listed. The role of minerals in the nutrition of animals is complicated because excess of some of them may also cause toxicities (Table 3.8) and there are, in addition, a number of rather complex interactions between different essential mineral elements.

As it is impossible to consider this subject in depth in a general textbook and as the subject is a dynamic one with new information constantly being made available, the reader who is particularly interested should consult specialized texts and the current literature.

Macroelements

Calcium

Calcium is the most common mineral element in the animal body. It is a constituent of bone and teeth and most living cells and tissue fluids. It also performs a role in the coagulation of the blood, the normal action of skeletal and heart muscle and in the regulation of the excitability of the nervous system.

The deficiency symptoms described in Table 3.6 may also be caused by a deficiency of phosphorus and/or vitamin D or by an abnormal calcium:phosphorus ratio. Normal ratios are 1:1 to 2:1 in mammals, but are rather wider in birds. Calcium metabolism is under the control of a hormone secreted by the parathyroid gland. There is a wide range in calcium requirement.

Phosphorus

Phosphorus is a constituent of bone, phospho-proteins, nucleic acids and phospholipids and has a role in calcium metabolism. Phosphorus deficiency (Table 3.6) is usually more common in cattle than in sheep. Pica (Table 3.6) is not a conclusive symptom of phosphorus deficiency as it may be caused by other factors.

Although cereal grains are a good source of phosphorus, much of what they contain may not be available for non-ruminants if it occurs in the form of phytates. These are more digestible by ruminant than by non-ruminant livestock.

Potassium

Potassium has a role, together with sodium, chlorine and bicarbonate ions, in the osmotic regulation of the body fluids, in which it functions primarily as the cation of cells. It also plays a part in nerve and muscle excitability and in

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Table 3.6 Macroelement deficiency symptoms and common sources of the element.

Element	Type of animal	Deficiency symptoms	Source of element and/or cure for deficiency
Calcium	Young animals	Rickets	Milk; green plants; fish and meat and bone by-products; ground limestone; steamed bone flour; dicalcium phosphate; rock calcium phosphate (the latter must be free of fluorine)
	Mature animals	Osteomalacia	
	Hens	Soft beak and bones; retarded growth; thin egg shells; reduced egg production	
	Milking animals	Milk fever	Intravenous injection of calcium gluconate
Chlorine	All animals	Decline in appetite; reduction in growth	As for sodium
	Hens	Feather picking; cannibalism	
Magnesium	Calves; milk fed for 5070 days	Tetany; death	Wheat bran; cottonseed cake; linseed cake
	Mature cattle and sheep	Grass staggers or hypomagnesaemic tetany;a when blood serum Mg 0.5 mg per 100 ml, death may result	Injection of magnesium sulphate; prophylactic; magnesium oxide at rate of 50 g per head per day; magnesium fertilizer on the pastures
Phosphorus	Young animals	Rickets; stunted growth	Milk; cereal grains; fish and meat and bone by-products; dicalcium phosphate; rock calcium phosphate
	Mature animals	Osteomalacia; low milk yield	
	All animals	Pica (depraved appetite); aphosphorosis; stiff joints; muscular weakness; low fertility; low milk yield	
Potassium	All animals	Unlikely to occur in practice	All green plants
	Calves fed on synthetic milk low in potassium	Severe paralysis	
	Chicks fed deficient diets	Retarded growth; tetany	
Sodium	All animals	Retardation of growth	Fish and meat and bone by-products; common salt
	Hens	Reduced growth and egg production	

Sulphur	All animals	Limits synthesis of the amino acids cysteine, cystine and methionine	Protein feeds; sodium sulphate; elemental sulphur

a The exact cause is unknown; it may be that dietary magnesium is poorly absorbed.

Table 3.7 Microelement deficiency symptoms and common sources of the element.

Element	Type of animal	Deficiency symptoms	Source of element and/or cure for deficiency
Chromium	Rats	Essential for normal glucose utilization	Widely distributed in feeds
	Calves	Supplementation has been shown to improve feed efficiency	
Cobalt	Cattle and sheep	Emaciation and listlessness occurs when cobalt content of forage less than 0.08 ppm; pining (vitamin B12 deficiency)	Cobalt salts; cobalt bullet containing 90% cobaltic oxide; vitamin B12
Copper	Cattle and sheep	Anaemia; poor growth; bone disorders; scouring; depigmentation of hair and wool; gastrointestinal disorders	Plant seeds; copper salts
	Cattle	'Teart', with excess molybdenum and sulphate	
	Lambs	'Swayback'. Lesions in brain and spinal column; muscular incoordination	
Fluorine	All animals	Dental caries	Fluorides in very small quantities
Iodine	All animals Livestock fed *Brassica* spp.	Endemic goitre or 'big neck'. Reproductive failure	Fishmeal; seaweed; iodized salt
Iron	Suckling pigs Hens Calves fed only milk for a long period Livestock with heavy parasite burden	Anaemia	Iron dextran injections for pigs Iron is well distributed in green leafy materials
Manganese	Cattle grazing sand and peat soils	Poor growth; leg deformities; poor fertility; frequent abortion	Only very small quantities of manganese are required Rice and wheat offals; manganese salts
	Pigs	Lameness	
	Chicks	Perosis or 'slipped tendon'	
	Hens	Reduced hatchability; reduced shell thickness in eggs; head retraction	
Molybdenum	All animals	None under practical farming conditions	Molybdenum salts
	Lambs on diets low in	Poor liveweight gain	

	molybdenum		
	Chicks on purified soybean diets	Poor growth	
Nickel	Chicks Pigs	Skin pigmentation changes; dermatitis	Cereal grains

(table continued on next page)

Table 3.7 Continued.

Element	Type of animal	Deficiency symptoms	Source of element and/or cure for deficiency
Selenium	Pigs	Liver necrosis due to to vitamin E deficiency	Vitamin E or sodium selenite
	Calves	Muscular dystrophy due to vitamin E deficiency	Vitamin E or sodium selenite
Silicon	Chicks	Poor growth and skeletal development	Widely distributed. Deficiencies under farm conditions unlikely
Vanadium	Chicks	Impaired growth, reproduction and lipid synthesis	Herring meal a rich source
Zinc		Unlikely to occur	
	Grazing animals when forages contain less than 0.004% Zn in DM		Widely distributed; yeast; bran and germ of cereal grains
	Pigs; intensively housed and fed on a dry diet	Parakeratosis; sub-normal growth; low efficiency of feed conversion; skin lesions	Zinc at the rate of 40100 ppm in the diet; as zinc carbonate or sulphate
	Chicks	Poor growth; poor feathering and calcification; skin lesions	

carbohydrate metabolism. The requirement for ruminants is estimated to be 0.51.0% of the diet but for lactating cattle under heat stress it may be as high as 1.2%.

Sodium

Like potassium, sodium is concerned with the osmotic regulation of body fluids, being the main cation of blood plasma and other extracellular fluids. The requirement is between 0.04 and 0.25% of the diet.

Chlorine.

Chlorine is associated with potassium and sodium in osmotic regulation and has an important role in gastric secretion in the true stomach of animals. A naturally occurring deficiency, distinct from potassium and sodium, has not been established.

Sulphur

Proteins containing the amino acids cystine, cysteine, and methionine, the vitamins biotin and thiamine and the hormone insulin all contain sulphur. Wool contains up to 4% sulphur. Small quantities of sulphates also occur in the blood. Deficiency of sulphur normally denotes a protein deficiency. When a non-protein nitrogenous compound such as urea is fed to ruminants additional sulphur may assist microbial synthesis of sulphur-containing proteins. Requirements are not well defined ranging from 0.10 to 0.32% of the diet.

Magnesium

Magnesium is closely associated with calcium and phosphorus in the skeletal structure, it is an activator of phosphates and it is also concerned with calcium metabolism. As adult animals possess only a very small available reserve of

Table 3.8 Toxic mineral elements.

Element or compound	Symptoms	Limits of concentration of element or compound
Cobalt	Unlikely to occur under practical farming conditions	>150 ppm
Copper	Continuous ingestion of excess copper leads to an accumulation in the body tissues; sheep are particularly susceptible; copper poisoning of this nature occurs in parts of Australia	Cattle 100 ppm Sheep 25 ppm
Fluorine	Causes fluorosis; teeth become pitted and worn; intake affected; fluorine is an accumulative poison; the major sources are water, rock phosphates used as a fertilizer, and fumes and effluents from industrial plant	>20 ppm in diet
Iron	Excessive intake causes digestive disturbances	1000 ppm. The least toxic of essential elements
Manganese	Toxic in very large doses; toxicity unlikely to occur under normal farming conditions	1000 ppm
Molybdenum	Induces copper deficiency under certain conditions	
Potassium	High intake of potassium may interfere with the absorption and metabolism of magnesium	3% diet. K toxicosis not a practical problem
Selenium	Causes toxicity in horses, cattle and sheep; known as 'alkali disease' or 'blind staggers' in the United States; dullness; stiffness of joints; lameness; loss of hair; some plants accumulate selenium; *Astragalus bisulcatus* may contain up to 4000 ppm on a dry-matter basis; the toxic effect is reduced when high-protein feeds are given to the livestock	540 ppm Toxicity modified by the dietary levels of As, Ag, Hg, Cu and Cd
Sodium chloride	Too high a level of intake causes excessive thirst, muscular weakness and oedema; salt poisoning quite common in pigs and poultry, particularly when water is limited	When water is limited; 4% hens, 2% chicks and 1% turkey poults
Zinc	Depression of feed intake and induction of a copper deficiency; unlikely to occur under normal farming conditions	>500 ppm in diet. Tolerance depends on relative content of Ca, Cu, Fe and Cd in diet

magnesium in their bodies they are very dependent upon a regular supply of this mineral. The requirements are, however, very variable, both within and between species.

Microelements

Iron

Most iron in the body occurs in the haemoglobin of the red blood cells, but it is also found in a blood serum protein known as siderophilin. This protein is believed to have a role in the transport of blood from one part of the body to the other. Iron is also found in the protein ferritin which is present in the spleen, liver, kidney and bone marrow. It is also a component of many enzymes and some flavoproteins.

The daily requirement of iron by the normal healthy animal is small. Anaemia due to iron deficiency could occur after severe haemorrhage or prolonged periods of feeding only milk to young ruminants, but normally anaemia only occurs in baby piglets. This is because sows' milk is particularly deficient in iron. The absorption of iron appears to be, to some extent, independent of the dietary source.

Copper

Copper is essential for the production of red blood corpuscles and for maintaining their activity. It is a component of many enzyme systems and is necessary for the normal pigmentation of hair, fur and wool. Storage takes place mainly in the liver, but copper is probably present in all body cells. As will be seen from Table 3.7, there are a variety of deficiency symptoms. In Australia a copper deficiency in lambs is known as 'enzootic ataxia' and is associated with the grazing of pasture with a low copper content (24 ppm Cu in the dry matter). Similar clinical symptoms occur in lambs in the United Kingdom suffering from a condition known as 'swayback' although the copper content of the grazings is normal (715 ppm Cu in the dry matter). A clinical condition known as 'teart', characterized by unthriftiness and scouring, occurs in cattle in the United Kingdom. A similar condition is known as 'peat scours' in New Zealand. The feeding of copper sulphate to animals controls this condition although the copper content of the pasture may be normal. However, these pastures do possess a high molybdenum content (20100 ppm compared with 0.53.0 ppm in the dry matter of normal pastures). It is believed that molybdenum affects copper retention by the animal, but limits it only in the presence of sulphate. Under these conditions, general recommendations as to copper requirements cannot be made without reference to molybdenum and sulphur concentration in soils and feeds.

Cobalt

Cobalt is required by microbia in the rumen for the synthesis of vitamin B12 and it is an activating ion in certain enzymic reactions. Sheep are more liable to exhibit cobalt deficiency than other types of livestock. Cobalt dietary requirements are of the order of 0.10.2 ppm.

Iodine

Iodine is a constituent of the hormone thyroxine that controls the metabolic rate of animals. Although a deficiency of iodine in the diet causes goitre, it is not the sole cause. Some feeds contain goitrogenic compounds, particularly *Brassica* spp., soybeans, peas, groundnuts and linseed. These goitrogenic compounds appear to block the absorption of iodine in what would otherwise be an adequate diet. Estimated requirements for ruminants vary from 0.05 to 0.8 ppm.

Manganese

Manganese is important as an activator of enzymic reactions concerned with carbohydrate, fat and protein metabolism. It is found in traces in most tissues. The highest concentrations are in the bones, liver, kidney, pancreas and pituitary gland. Manganese deficiency is not the only factor concerned in the clinical condition known as 'perosis' in chicks (Table 3.7). The condition is

aggravated by high intakes of calcium and phosphorus. The minimum dietary requirements are not precisely known but probably vary between 20 and 40 ppm.

Zinc.

Zinc appears to be present in all tissues and is concerned in some enzymic reactions. The clinical condition in pigs known as parakeratosis (Table 3.7) is aggravated by increased calcium levels in the diet and decreased by reduced calcium and improved phosphorus levels.

Molybdenum

Molybdenum is a constituent of the enzyme xanthine oxidase that has an important role in purine metabolism, of nitrate reductase and of a bacterial hydrogenase. It has also been found to be a constituent of another enzyme, aldehyde oxidase.

Selenium

The relationship between selenium and vitamin E (Table 3.7) is complex as both can prevent certain dietary disorders. Selenium can replace sulphur in the amino acids methionine and cystine found in seleniferous plants. The element is an essential constituent of an enzyme that helps to protect cellular membranes from oxidative damage. It is also suggested that selenium plays a role in reproduction, in prostaglandin synthesis and in essential fatty acid metabolim. Selenium and vitamin E are both needed for adequate immune responses (McDowell, 1997).

Fluorine

Fluorine is distributed throughout the body but is concentrated in the bones and teeth. Although the element is essential it is also very toxic. Essential requirements are very low. Ruminants are more susceptible to fluorosis than non-ruminants and cattle are less tolerant than other grazing ruminants.

Silicon

Silicon appears to be important in the formation of cartilage and in other processes involving mucopolysaccharides. It is widely available.

Chromium

The element may have a role in lipid and protein synthesis. Supplementary chromium has been shown to improve growth and efficiency in 'stressed' calves (Mowat & Chang, 1992).

Nickel

The physiological effects on chickens and pigs have only been produced under laboratory conditions. A possible role in nucleic acid metabolism is not fully established.

Vanadium

Deficiency symptoms have been demonstrated in rats and chickens but to date there is little information on the vanadium content of feeds.

In tropical environments mineral deficiencies may be enhanced by the animal losing considerable quantities of the elements during sweating or by dribbling saliva. For example, Bonsma (1940) stated that unacclimatized bulls may dribble 1318 litres of saliva a day and lose 5171 g of minerals. However, it is not considered that this is a problem in acclimatized livestock.

Cereals, and to a lesser extent cereal by-products, normally possess a low proportion of calcium and a relatively high proportion of phosphorus. Most forages possess more calcium than phosphorus. Legume forages normally possess a relatively high calcium content and browse is usually relatively rich in all mineral elements. Feeds of animal origin are usually well supplied with minerals.

Knowledge of mineral deficiencies in tropical regions has improved in recent times (McDowell, 1985, 1997). In Guyana very large areas are known to be deficient in minerals as are extensive areas in Brazil and Central America. There is at present a major project, with headquarters at the University of Florida, concerned with ascertaining the extent of mineral deficiencies in tropical America and elsewhere. In Africa it is known that very large areas of range, particularly in East, Central and South Africa, are deficient in phosphorus. In Kenya and Zaire cobalt-deficient areas have been identified. It is likely that the soils in almost all humid tropical regions are deficient to a greater or lesser degree in one or more mineral elements. Obviously a very great effort will be required to map all mineral-deficient areas in the tropics. In the interim period the livestock owner can insure himself against mineral deficiencies by the feeding of complete mineral supplements (McDowell *et al*., 1984).

Nomadic peoples in the tropics have known for a very long time that it was necessary for them to insure against mineral deficiencies, although their livestock range over wide areas thus reducing the risk of mineral deficiency in any one locality. For example, the Baggara people in the western Sudan know which of their ranges are 'salty' and they herd their animals so that they spend as long a time as is possible on the 'salty' range. Nomadic herders also often carry salt with them for their livestock and/or visit areas where there are edible earths. Certainly earth eating, or *geophagia*, is a very common habit of both domestic and wild animals in the tropics. It is interesting that chemical analyses of edible earths from both East and West Africa, although demonstrating the variety of their mineral constituents, have failed to establish direct links between known mineral deficiencies and geophagia (French, 1945). In the humid forest regions of South and Southeast Asia salt has been used to attract wild cattle of the *Bibos* spp. to breed with domestic cattle and it has been suggested that the domestication of *Bibos* spp. cattle may have been originally achieved by man attracting the wild cattle by the provision of salt in highly mineralized earths (Simoons & Simoons, 1968).

It is advisable that all grazing livestock be fed a simple mineral supplement and that all yarded and/or housed livestock should be fed complete mineral supplements.

A very suitable and simple mineral supplement for ruminant livestock is:

Common salt	40 parts
Ground chalk, limestone or shell	40 parts
Steam bone flour	20 parts

This mixture should be fed *ad libitum* to grazing animals. If concentrates are fed the mixture may be added to them at the rate of 23% of the total ration. If there is a known mineral deficiency in the regionapart from calcium, phosphorus, sodium and chlorinethen a salt of the specific mineral that is known to be deficient should be added to the above mixture at the recommended rate. The indiscriminate feeding of complete mineral mixtures to grazing animals is not advocated, unless the latter are exhibiting some symptoms of mineral deficiency. However, it should be realized that in this context the deficiency symptoms may be subclinical in their manifestation, i.e. poor growth and low fertility.

Range livestock may have to be supplemented in the dry season, with other nutrients, and where ureamolassesmineral blocks or liquid feeds are used the animals will be able to obtain their mineral requirements from the block or liquid feed.

Yarded or housed livestock must be considered to be in a different category. They should all receive rations containing complete mineral supplements. In most tropical countries the livestock-feeding industry has now developed to the extent that complete mineral mixtures are readily available. These can be delivered to the animal by a variety of methods: some of the more recently developed and efficient being slow release sources of specific minerals in soluble glass or other boluses. If mineral mixtures are not readily available then the livestock owner requiring information on the composition of complete mineral mixtures should consult his local extension adviser.

Vitamins

Vitamins are essential food substances that are required in very small quantities by animals. Those known to be of any importance in animal nutrition are listed in Table 3.9. For convenience they are classified in two groups: fat soluble and water soluble. Details of the clinical symptoms that deficiencies of these vitamins may cause, together with some of their common sources, are listed in Table 3.10. Brief accounts of the roles that these essential foodstuffs occupy in the metabolism of animals are summarized below.

Fat-Soluble Vitamins.

Vitamin A

Animals can synthesize vitamin A from the precursors found in plants. These are known as carotenoids, the most widely distributed being b-carotene. Vitamin A is a constituent of the pigment of the red cells of the retina of the eye. It is concerned with the maintenance of the mucous membranes of the respiratory tract, intestinal tract, urethra, kidneys and eyes and also plays a role in bone formation.

Species and breeds within species differ in their ability to convert carotenoids into vitamin A. Sheep and buffaloes are efficient converters while some breeds of cattle such as the Jersey are relatively inefficient converters, their butterfat and body fat containing large quantities of the unconverted yellow carotenoids.

Vitamin A is stored in the liver so that deficiency symptoms may not appear for quite a long period after animals are fed on a carotenoid-deficient diet.

In the monsoonal and dry tropics grazing ruminant livestock may suffer from vitamin A deficiency towards the end of prolonged dry seasons. It is unlikely that grazing animals in the wet tropics suffer from a deficiency of the vitamin. All yarded or housed livestock should receive adequate green feed or synthetic vitamin A supplements. Poultry, in particular, are likely to suffer from a deficiency of this vitamin.

Vitamin D

Vitamin D facilitates the deposition of calcium and phosphorus in the bones and improves the absorption of these elements from the intestinal tract. Grazing animals in the tropics are unlikely

Table 3.9 Vitamins of importance in animal nutrition.

Fat soluble	
A	retinol; precursor; carotenoids, the most important being b-carotene
D	there are ten to twelve different forms: only ergocalciferol (D2) and cholecalciferol (D3) are of importance
E	collective name for a group of closely related compounds known as tocopherols; a-tocopherol is the most important
K	collective name for a number of compounds: phylloquinone (K1) is the most important
Water soluble	
B complex	
B1	thiamin
B2	riboflavin
Nicotinamide	formerly known as nicotinic acid or niacin
B6	pyridoxine: exists in three forms that are interconvertible
Pantothenic acid	
Biotin	
Choline	
Folacin	collective name for a number of derivatives of folic acid
B12	cyanocobalamin: several forms of the vitamin are known

C 1-ascorbic acid

Table 3.10 Vitamin deficiency symptoms and common sources of the vitamin.

Vitamin	Type of animal	Deficiency symptoms	Source of vitamin and/or cure for deficiency
A	Cattle	Rough coat and scaly skin; excessive watering of eyes culminating in xerophthalmia; low fertility; abortion	Green, leafy materials; fish-liver oils; synthetic vitamin A
	Pigs	Poor growth; low fertility	
	Poultry	Retarded growth; staggering gait; low egg production and hatchability	
	All animals	Secondary bacterial infections	
D	Young animals	Rickets	Synthesis in the skin of outdoor-managed animals; sun-dried feeds such as hay; fish-liver oils
	Older animals	Osteomalacia	
E	Young cattle and lambs	Muscular dystrophy	Green leafy materials; cereal grains; synthetic a-tocopherol; selenium salts
	All animals	Reproductive failure	
	Chicks	Encephalomalacia; exudative diathesis	
K	Chicks	Delayed clotting time of the blood	Green leafy materials; fish meal; K2 synthesized by bacteria in digestive tract
B1	Chicks	Polyneuritis	Cereal grains; generally wide distribution in feeds
B2	Pigs	Loss of appetite; severe diarrhoea; poor growth	Green leafy material; milk; dried whey; yeast; liver
	Chicks	Curled toe paralysis	
	Hens	Decreased hatchability of eggs	
Nicotinamide	Pigs	Poor growth; enteritis; dermatitis	Any source of tryptophan as nicotinamide can be synthesized from it
	Poultry	Black tongue	
B6	Pigs	Poor growth rate; anaemia; convulsions	Widely distributed in feeds so that deficiencies are unlikely to occur in practice
	Chicks	Poor growth; convulsions	
	Hens	Poor egg production; reduced hatchability	
Pantothenic acid	Pigs	Poor growth; dermatitis; characteristic 'goose-stepping' gait	Widely distributed in feeds; deficiencies unlikely to occur in farm practice
	Chicks	Poor growth; dermatitis	
Biotin		No deficiency symptoms seen under	Widely distributed in feeds;

		practical farming conditions	also usually synthesized in the alimentary tract
Choline	Chicks	Perosis or 'slipped tendon' (see Table 3.7); can be prevented by feeding choline	Widely distributed in feeds and can be replaced with methionine and betaine in the diet

(table continued on next page)

Table 3.10 Continued.

Vitamin	Type of animal	Deficiency symptoms	Source of vitamin and/or cure for deficiency
Folacin	Chicks	Anaemia; poor growth	Widely distributed in feeds; also synthesized by intestinal microbia
B12	All animals	Poor growth	Foods of animal origin; synthesized by intestinal microbia when cobalt is present; also synthesized in poultry litter
C	All animals	None	Farm animals do not require any dietary source of this vitamin as they can synthesize it

to suffer from vitamin D deficiency as sunlight helps to synthesize it in the skin. Housed animals without access to sunlight should receive supplements.

Vitamin E

Vitamin E acts as a non-specific antioxidant and is associated with selenium. It protects essential phospholipids. Deficiency of this vitamin can cause a muscular dystrophy in calves and lambs; this can be cured by the administration of either vitamin E or a selenium salt.

As vitamin E is widely distributed, particularly in green leafy material, deficiencies are unlikely to occur in grazing animals in the humid tropics. Housed animals should receive adequate green feed or synthetic vitamin E supplements.

Vitamin K

This is essential for the synthesis in the liver of prothrombin, the inactive precursor of thrombin. This enzyme converts the protein fibrinogen in blood plasma into fibrin, the insoluble protein that holds blood clots together. Symptoms of vitamin K deficiency have not been reported in ruminants or pigs under practical farming conditions. A disease of cattle associated with the feeding of fermented sweet clover (*Melilotus alba*), that contains a compound known as dicoumarol, can be cured by the administration of vitamin K. Poultry feed should contain up to 2.5% dried green forage material to ensure that the birds do not develop deficiency symptoms.

Water-Soluble Vitamins

Vitamin B1

A derivative of vitamin B1 (thiamin pyrophosphate) is a coenzyme involved in the oxidative decarboxylation of several compounds and in the synthesis of valine in bacteria, yeasts and plants. Ruminants can synthesize the vitamin, and because of the fact that cereal grains are a rich source of the vitamin, pigs and poultry are unlikely to suffer deficiencies. In some areas of the humid tropics the feeding of raw fish to livestock could induce a thiamin deficiency as some fish contain an enzyme known as thiaminase that destroys thiamin in the remainder of the feed.

Vitamin B2

Riboflavin is an important constituent of the flavoproteins. These are concerned in carbohydrate metabolism. In practice, deficiencies may occur in the diets of pigs and poultry fed mainly on cereals. As poultry excreta are often richer in riboflavin than their diet, the floor brooding of chicks is advantageous when high cereal content diets are fed.

Nicotinamide

The precursor for this vitamin is the amino acid tryptophan. The vitamin functions as part of two important coenzymes that are involved in hydrogen transfer in living cells. In practice, deficiencies are only likely to occur where pigs and poultry are fed very high maize content diets.

Vitamin B6.

The vitamin exists in three interconvertible forms; pyridoxine, pyridoxal the aldehyde derivative and pyridoxamine the amine. Pyridoxal phosphate serves as a coenzyme in a number of metabolic reactions. Deficiencies do not normally occur under practical farming conditions.

Pantothenic Acid

This vitamin is a constituent of coenzyme A. Because of the wide distribution of the vitamin in feeds, deficiencies are rarely reported in farming practice.

Biotin

Biotin dependent enzyme systems are important in many metabolic systems including fatty acid synthesis. As a consequence, a deficiency of this vitamin could result in a variety of clinical symptoms. On account of its wide distribution in feeds, however, biotin deficiencies are rare in farming practice.

Choline

It has a number of functions: a component of lecithin that plays a role in cellular structure and activity; a part in lipid metabolism in the liver; and a component of acetylcholine that is concerned with the transfer of nerve impulses. As it can be replaced in metabolic functions by the amino acids methionine and betaine and it is widely distributed in feeds, deficiencies are rare in farming practice.

Folacin

The term 'folacin' is used to describe a number of compounds that are derivatives of folic acid. They play a role in various enzyme systems and are synthesized by intestinal bacteria. In practice only chicks are likely to suffer from deficiencies although the prolonged oral administration of sulpha drugs may induce deficiency symptoms in other livestock due to the depression by the drug of bacterial synthesis of the vitamin.

Vitamin B12

Coenzyme forms of vitamin B12 are of importance in many metabolic reactions, particularly in propionic to succinic acid metabolism in the ruminant. As long as adequate cobalt is available and its utilization is not blocked, vitamin B12 can be synthesized by ruminants and non-ruminants. Synthesis of vitamin B12 can also apparently take place in deep litter in poultry houses.

Vitamin C

All domestic livestock can synthesize this vitamin. Under climatic stress, however, demand for vitamin C may outrun normal synthesis so that a dietary supplement may be beneficial. It has an important role in the oxidation-reduction mechanisms of living cells.

It will be realized from these brief notes that, except under special circumstances, vitamin deficiencies are rare in free-grazing animals. However, the situation with housed animals is different. Non-ruminant livestock and particularly poultry are liable to suffer from vitamin deficiencies if their rations are not supplemented. Commercial poultry rations are usually fortified with adequate vitamins, and farmers who mix their own rations can normally purchase vitamin premixes in most tropical coun-

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tries. The small pig and poultry farmer with no access to commercially mixed rations of vitamin premixes should always provide some green feed for his livestock. Housed poultry are less likely to suffer from vitamin deficiencies if they are managed on deep litter.

Additives

Compounders of animal feeds normally add vitaminmineral supplements to their rations. They have also been adding specific amino acids, such as lysine, to pig rations that are considered to be deficient in the amino acids. These constituents can all be considered essential feed additives. In addition, however, compounders have been increasingly adding, in those countries where it is legal, other substances such as antibiotics, hormones, arsenicals, tranquillizers, detergents andin the case of pig rationsadditional copper sulphate.

Antibiotics

These are chemical substances produced by microorganisms which in minute quantities inhibit the growth of other microorganisms or even destroy them. Antibiotics can be classified into two groups: broad-spectrum antibiotics that inhibit the growth of a wide range of microorganisms and narrow-spectrum antibiotics that only inhibit the growth of one or a small number of other microorganisms.

It has been shown that low-level intakes of antibiotics can improve the productivity of pigs, poultry and young calves.

In pigs the average response to feeding antibiotics has been a 1015% increase in growth rate and a 35% improvement in the efficiency of feed utilization. The response is greatest where standards of hygiene and management are poor, in young rather than older animals and when all-vegetable protein diets are fed. The optimum level of inclusion of antibiotics is considered to be within the range of 5 to 15 g per tonne of the rations and it is generally recommended that feeding should continue throughout the life of the fattening pig since abrupt withdrawal may reduce liveweight gain and nullify the initial advantages.

With poultry the degree of response to antibiotics varies with the standards of health and management and the age of the birds. Turkey poults respond better than chicks with increases of up to 15% in growth rate being recorded.

In young calves the inclusion of antibiotics in the diet reduces the incidence and severity of scours and improves growth rates. There is also some evidence that the inclusion of antibiotics in the rations of mature ruminants, fed rations that are composed mainly of concentrates, can be of value.

It is probable that the improvements in productivity achieved by the use of antibiotics are mainly due to the suppression of subclinical infections, although there may also be other effects. The disadvantage of using antibiotics in feeds is that resistant strains of microorganisms may ultimately develop. However, the prolonged use of antibiotics in livestock feeds at the normal recommended levels is unlikely to become a health hazard to the consumers of animal products.

In the United Kingdom and in some other countries recommended inclusion rates of feed antibiotics have been promulgated by the authorities. Readers interested in maximum and recommended inclusion rates for pig, poultry and calf rations should consult local extension and public health officials.

Hormones.

A number of synthetic and naturally occurring hormones have been shown to possess growth promoting properties. These include anabolic steroids, beta agonists, growth hormone (GH), growth hormone releasing factor (GRF) and insulin-like growth factors.

Anabolic steroids, such as oestradiol, improve the growth rate of cattle by 818% (Roche & Quirke, 1986) but their use is controversial. Effective delivery systems, such as compressed pellets and silastic rubber ear implants have been devised.

Beta agonists such as Cimaterol reduce the fat

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content and increase the lean content of the animal's body. The effect may be due to a reduction in muscle protein breakdown or to a small increase in muscle protein synthesis. Buttery (1996) has stated that it is not yet known what effect metabolic modifiers have on overall efficiency in the utilization of nutrients, but it is known that ruminants only demonstrate increased growth and additional gain of lean meat when they are fed a diet containing adequate nutrients. It is not yet known what effect metabolic modifiers have on the efficiency of utilization of nutrients.

The use of growth hormones (GH) is still in the experimental stage, although as early as 1937 it was reported that the injection of a crude pituitary extract containing somatotropin improved milk production. It is the advent of recombinant DNA technology that has led to the production of adequate supplies of a biosynthetic bovine somatotropin. In cattle the use of this hormone increases milk production by 1020% over the complete lactation. First reports on its use in a subtropical environment suggest the milk production response is lower and the stress higher (Staples *et al*., 1988). The hormone also affects the growth rate, feed efficiency and the partition of fat and lean meat in the carcase. These effects are reviewed by Hart & Johnsson (1986).

There is some experimental interest in the use of the growth hormone releasing factor (GRF) and insulin-like growth factors. The effects of the GH on growth are considered to be mediated by the latter compounds.

The use of hormones is a very controversial subject and their present use for implantation, injection or in feeds is illegal in many countries. The most serious criticism is that there might be a human health hazard from possible carcinogenic properties of residues of the hormones in milk and carcases.

Arsenicals

Some compounds containing arsenic, such as arsanilic acid, sodium arsanilate, arsenic acid and arsenobenzene, appear to possess growth-promoting properties. This is probably due to their effect on the intestinal microbia. As arsenic is an accumulative poison very considerable precautions must be taken if these compounds are to be used in feeds, although there is no evidence that feeding them produces carcases with unacceptably high tissue concentrations of arsenic.

Tranquillizers

There is evidence that the feeding of some of these compounds, which are normally used to reduce hypertension and nervousness, may improve liveweight gain.

Detergents

Evidence for the use of some of these compounds as growth promoters is contradictory.

Copper Sulphate

The use of additional copper sulphate in the diet of pigs is discussed in Chapter 14.

Other Additives

There are also a number of other feed additives, such as Nitrovina guanidine derivativeand quinoxaline compounds, that appear to improve the growth rate of some classes of livestock. Coccidiostats used in poultry rations and the drugs used in the treatment for histomoniasis in turkeys also act as growth stimulants.

Apart from the use of mineralvitamin premixes, the fortification of amino-acid-deficient rations with individual amino acids and the use of feed antibiotics, the feeder in the tropics should be very cautious in his use of the very large number of additives that are available. This is because virtually all investigational work on additives has been conducted in the temperate zone and little is known of the effects of many of them on animals managed in a tropical environment.

Evaluation of Foods

Proximate Analysis

Although it is possible with modern equipment and methods to determine the individual components of foods, most of the information that we possess on their composition is based on what is known as *proximate analysis*. In this system of analysis the food is divided into six fractions. These are as follows:

(1) *Moisture*: including any volatile acids and bases that may be present.

(2) *Ash*: this fraction includes essential and inessential mineral elements.

(3) *Crude protein* (CP): this fraction includes protein, amino acids, amines, nitrogenous glycosides, glycolipids, B vitamins and nitrates.

(4) *Ether extract*: this fraction includes fats, oils, waxes, organic acids, pigments, sterols and the fat-soluble vitamins.

(5) *Crude fibre* (CF): this fraction includes insoluble cellulose, hemicellulose and lignin.

(6) *Nitrogen-free extractives*: these include soluble cellulose, hemicellulose and lignin, sugars, fructosans, starch, pectins, organic acids, resins, tannins, pigments and water-soluble vitamins.

The moisture content is determined by drying food to a constant weight at 100°C. The ash content by ignition of food at 500°C until all the carbon has been removed. The CP content is calculated from the nitrogen content of the food, determined by some modification of the Kjeldahl sulphuric acid digestion technique. Where N is the total nitrogen content, $N \times 6.25$ is assumed to be the CP content of the food. The ether extract content is determined by subjecting the food to continuous extraction with petroleum ether for a defined period. The residue after the evaporation of the ether is the ether extract content. The CF content is determined by subjecting the residual food from the ether extraction to successive treatments with boiling acid and alkali of defined concentration. The organic residue is the CF content. The nitrogen-free extractives content is determined by subtraction of the sum of the percentages of moisture, ash, CP, ether extract and CF from 100.

Digestibility

Although the potential value of a food can be approximately determined by proximate analysis, the actual value of the food to the animal can be determined only if the digestibility is known. Digested food is that portion of the feed intake that is not excreted in some manner and which is assumed to be absorbed by the animal. Digestibility can be measured by the use of *in vivo* or *in vitro* methods.

In *in vivo* methods the food under investigation is fed to an animal and the total input (I) and output (O) of the food constituents are measured. The digestibility can be calculated using the following formula:

$$\text{Percentage digestibility} = \frac{I - O}{I} \times 100$$

In such digestibility trials there is a need for adequate replication, for uniformity in the management of the animals and for suitable collection equipment.

Special methods using indicators have to be used for determining digestibility in grazing animals. Suitable indicators are lignin and chromic oxide. If indicators are used, then when If represents the g indicator per kg faeces and Ir the g indicator per kg of ration,

$$\text{Percentage digestibility} = \frac{If - Ir}{If} \times 100$$

One difficulty in determining digestibility coefficients using grazing livestock is that the latter are selective in their grazing habits, so that the plants or portions of plants that they consume are not necessarily representative of the pastures that they are grazing. The problem can be overcome to some extent by using animals fitted with an oesophageal fistula. Samples of the feed actually consumed are taken from time to time through the fistula and the digestibility of these samples determined by an *in vitro* method.

As any type of *in vivo* digestibility determination is costly and time consuming, efforts have been made to reproduce in the laboratory the reactions that take place in the digestive tract of animals. As a consequence, *in vitro* methods have been devised that are relatively cheap and rapid to perform. The standard *in vitro* digestibility determination is made in two stages. First, a finely ground sample of feed is incubated for 48 hours with buffered rumen liquor in a tube under anaerobic conditions. Second, the bacteria is killed by acidifying with hydrochloric acid to pH 2.0 and then the sample is digested by incubating with pepsin for 48 hours. Various modifications of this procedure may be used. One is to replace the rumen liquor (which must vary between samples) with a fungal cellulose preparation. Digestibilities determined by *in vitro* methods are usually lower than those determined on the same feed by *in vivo* methods so that correction factors must be used. Interested readers should consult standard textbooks and publications for details of the methods employed in both *in vivo* and *in vitro* digestibility determinations.

Digestibility coefficients determined by *in vivo* and *in vitro* methods are not completely accurate and should be termed *apparent digestion coefficients*. There are at least two errors in the procedures. First, methane arising from the fermentation of carbohydrates is lost by eructation and secondly not all faeces consist of undigested food residues. Nevertheless, apparent digestion coefficients can be useful guides in feeding practice.

Digestibility is influenced by:

(1) The chemical composition of a specific feed and the composition of different feeds in a mixed ration.

(2) The level of feeding. High levels of input increase the rate of passage of feeds through the digestive tract, depressing digestibility.

(3) The species of animal consuming the feed. As can be seen from the data in Table 3.11 digestibility coefficients for the same feed will vary for different animals.

(4) The processing of the feed. This can have a profound effect on digestibility. There is also an interaction between species and processing as cereal feeds should be ground before feeding to pigs and crushed for cattle. The processing of roughages in order to improve their digestibility is of major interest in the tropics where a high proportion of livestock have to exist on roughage feeds. The subject will be further discussed in the sections entitled 'Feeding standards and requirements' and 'Types of feed available'.

Energy Content.

The ability of the food to supply energy is of major importance in the evaluation of its nutritive value. The total energy content of a food is known as the *gross energy*. There are, however,

Table 3.11 The range of digestibilities of the dry-matter (DM) content of guinea grass (*Panicum maximum*) in cattle, water buffaloes, sheep and goats. (*Source*: Devendra, 1971.)

Type of livestock	Range of digestibility of the DM of guinea grass	Site of trials
Cattle	5160	Uganda, India and the Philippines
Water buffaloes	5864	Philippines
Sheep	5059	Australia and Puerto Rico
Goats	57	Malaysia

many losses of energy within the body due to defaecation, urination, the production of methane in the digestive tract of ruminants and the heat increment of specific dynamic action of the food. These are shown diagrammatically in Fig. 3.2. That fraction of the gross energy that remains available to the animal for maintenance and productive purposes is known as the *net energy*. The first demand on net energy is for maintenance of the body processes, whilst that remaining may be used for productive purposes.

Total heat productionthat is the heat released by specific dynamic action of the food, together with the heat resulting from the maintenance of body processes and productioncan be a source of major difficulty for the animal in the tropics (see Chapter 1).

In order to measure the extent to which the metabolizable energy in a food is utilized by an animal it is necessary to measure the animal's heat production or energy retention. These are measured by a variety of methods. The most important are direct calorimetry, in which the heat production of an animal is directly measured, and indirect calorimetry where measurements are made of the respiratory exchange and heat production estimated from oxygen consumption. There are also a number of other indirect methods. Readers interested in details of the methods employed should consult appropriate texts, some of which are included in the further reading list at the end of this chapter.

Energy Systems

In former editions of this book the European starch equivalent (SE) system and the American total digestible nutrients (TDN) system were described and used throughout the text. Since the 1980s, however, the number of energy systems that can be used has increased. The SE system has been replaced in the United Kingdom by a metabolizable energy system devised by Blaxter (1962) and incorporated in a refined form in an Agricultural Research Council (1980) publication.

Internationally the introduction of this new system has not simplified the situation. Several revised systems are also used in continental

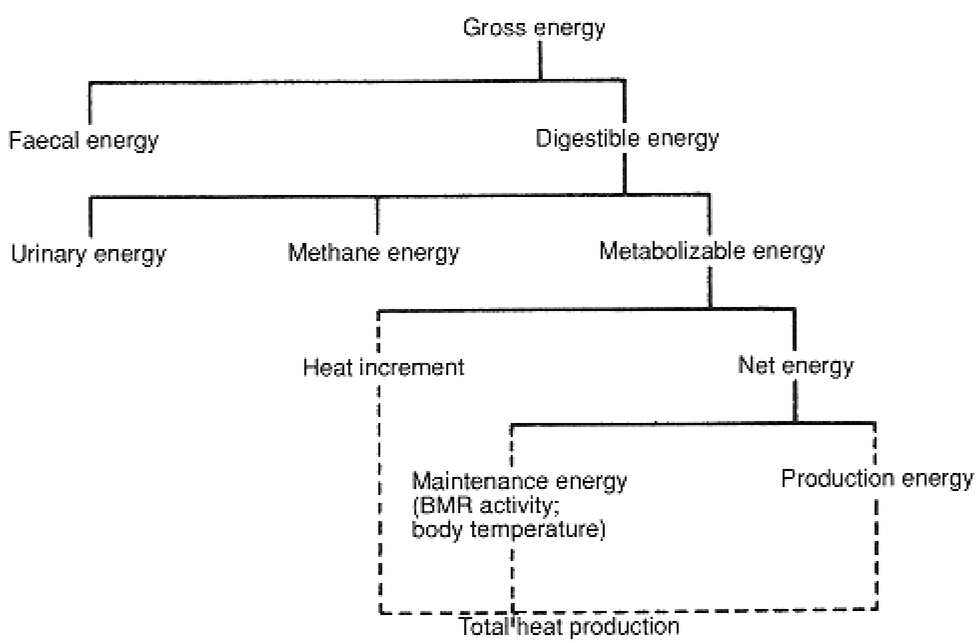

Fig. 3.2
Diagrammatic representation of the utilization of energy in the animal.
(Source: McDonald *et al*., 1973.)

Europe and a 'net energy for lactation' system is being introduced in the United States.

The SE system is based on net energy. The value of the food is not expressed in absolute terms but as the fat-producing ability of a food relative to the fat-producing ability of a unit of starch. The SE of a food is therefore:

$$\frac{\text{Weight of fat stored per unit weight of food ingested}}{\text{Weight of fat stored per unit weight of starch ingested}} \times 100$$

The calculation can be expressed on a net energy basis by assuming that 1 g of fat contains 9.5 kcal of energy. TDN, however, is calculated by adding together the quantities in 100 units of food of the digestible crude protein, crude fibre, nitrogen-free extractives and the digestible ether extract multiplied by 2.25. In Table 3.12 calculations are shown of the respective SE and TDN values of barley meal.

In the new United Kingdom system the energy value of foods is expressed in terms of metabolizable energy (ME) and the energy value of rations is calculated by adding up the contributions of the individual food constituents. The energy requirements of the animal are, however, expressed in absolute terms as net energy. A series of equations predicting the efficiency of utilization of metabolizable energy for maintenance, growth and lactation is used to link feed metabolizable energy values and animal net energy requirements. The United Kingdom system is used for evaluating the feed requirements of ruminants throughout this book. Further information on the system is provided by the Agricultural Research Council (1980) and McDonald *et al*. (1981).

Energy values for pigs, if required, are usually stated in terms of TDN or metabolizable energy. The energy value of poultry foods is normally expressed in terms of metabolizable energy as this component is relatively easily measured.

As there is no universal agreement on one system for determining energy values, readers should familiarize themselves with and utilize the system currently used in their country.

Protein Content

As stated previously the CP content of a feed measures both the true protein content and the non-protein nitrogen content. In practice this is not very important as in ruminants the non-protein nitrogen fraction can be synthesized into protein by the microbia of the digestive tract and the diet of non-ruminants does not usually contain substantial quantities of non-protein nitrogen. True protein (TP) can be determined chemically. The apparent digestible crude protein (DCP) content can also be determined using the digestibility techniques discussed in a previous section.

Table 3.12 Calculations of the starch equivalent (SE) and total digestible nutrients (TDN) of barley meal from data on digestible nutrients. (*Source*: McDonald *et al*., 1973.)

Constituent	% Digestible nutrients in dry matter	SE factor	SE	TDN
Digestible crude protein	12.6			12.6
True protein	11.3	0.94	10.6	
Ether extract	1.6	2.12	3.4	3.6
Crude fibre	0.2	1.00	0.2	0.2
Nitrogen-free extractives	65.8	1.00	65.8	65.8
Totals			80.0	82.2

Non-Ruminants

As the DCP content of a feed is not an entirely satisfactory assessment of protein value for an animal, because the efficiency with which a protein is used differs according to its source, several other methods of evaluating protein have been devised. The major ones are: the protein efficiency ratio (PER), the gross protein value (GPV), the protein replacement value (PRV) and the biological value (BV).

Biological value is probably the method that is mainly used. It may be calculated from the formula:

$$\frac{N-(FN-MFN)-(UN-EUN)}{N-(FN-MFN)}\times 100$$

where *N* is nitrogen intake, *FN* is faecal nitrogen, *MFN* is metabolic faecal nitrogen, *UN* is urinary nitrogen and *EUN* is endogenous urinary nitrogen. Some BVs of the proteins of common foods are shown in Table 3.4.

The BV of a food protein depends upon the number and the types of amino acids present in the protein. The closer the amino acid composition of the food protein approaches to the amino acid composition of the body protein the higher will be its biological value. It will readily be seen that the BV of a mixture of foods will not be a mean of the individual BVs. In general, animal proteins will possess higher BVs than plant proteins.

Amino-acid estimations can be made by chemical (lysine) or biological methods (methionine and cystine) or by microbiological assay. Relevant textbooks should be consulted as to the methods employed.

In practice a CP estimation is normally used for the evaluation of the protein content of feeds in pig and poultry rations, together with an assessment of the ability of the proteins to supplement the known amino-acid deficiencies of the cereal part of the rations.

Ruminants

Proteins in ruminant rations have in the past been evaluated in terms of CP or DCP. The concept of protein equivalent (PE) was introduced to allow for the value of the non-protein nitrogen fraction in the CP. The PE was calculated as follows:

$$\text{PE}=\frac{\text{Percentage digestible TP} + \text{percentage digestible CP}}{2}$$

There does not appear to be any particular justification for the use of PE rather than DCP in the evaluation of the protein content of ruminant feeds.

New Concepts in the Evaluation of the Protein Content of Ruminant Feeds

For many years there has been dissatisfaction with the concept of '*digestible protein*' in ruminant nutrition as it fails to adequately represent the complexity of the nitrogen economy in the ruminant digestive tract. This has been particularly the case in the tropics where ruminant livestock are so often fed large quantities of feed, high in fibre and low in CP content.

Any assessment of protein quality in ruminant feeds is difficult on account of the extensive degrading and synthesizing activities of rumen microorganisms. The latter are responsible for providing the major part of the energy requirements of the host animal by transforming dietary carbohydrates into acetates, propionates and butyrates. For this to occur there has to be large-scale synthesis of microbial protein. Nitrogen for this synthesis is obtained by the breakdown of nitrogenous substances in the feed to produce amino acids and ammonia. Although some ammonia may be used in the synthesis of the microbia, the major part is absorbed into the blood stream and converted into urea, only part of which is returned to the digestive tract via the saliva glands. The other part is excreted in urine.

Microbial protein, whether of bacterial or protozoal origin, has a BV of about 80. This protein eventually passes from the rumen to the abomasum and on to the small intestine, where it is broken down into its constituent amino acids.

Some or all of these are absorbed and utilized to satisfy the nitrogen requirement of the host animal.

Given the complexity of rumen utilization of dietary nitrogen, alternate concepts have been proposed and are being used for expressing ruminant protein requirements. One is the metabolizable protein (MP) system. Webster (1996) concluded that this is a satisfactory and improvable system but it has not yet been thoroughly tested. Readers requiring detailed information should consult McDonald *et al*. (1988) and Webster (1996).

Feeding Standards and Requirements

Feeding standards for the different classes of tropical livestock, when and where they are known, are detailed in the chapters concerned with the various types of livestock in Part II of this text. Information on temperate zone feeding standards, that with some modifications have generally been used in the tropics, is available in Morrison (1957), Agricultural Research Council (1967; 1975; 1980), National Academy of SciencesNational Research Council (1971; 1973; 1975; 1976; 1977) and McDonald *et al*. (1995).

Limitations on the Use of Temperate-Type Feeding Standards in Tropical Environments

There are specific difficulties in applying conventional temperate-type feeding standards to the nutrition of livestock, particularly ruminants, in tropical climates. One, is that in hot climates, heat produced within the animal's body has in some manner to be dissipated in order to avoid abnormal and dangerously high body temperatures, whereas in temperate climates it can usually be conserved in order to maintain normal body temperature. Another, is that although the new concepts for assessing nutrient requirements for ruminants discussed previously are being applied in the temperate zone, they are not necessarily so applicable in the tropics, particularly where the major proportion of the feed is high in fibre and low in protein and available energy.

Effect of Heat Increment

Methods by which livestock in the tropics cope with the heat increment have been discussed in Chapter 1. Heat stress causes a rise in the basal metabolic rate and this may increase the catabolism of protein in the body tissues, causing a higher requirement for amino acids per unit energy of nutrient substrate. In this situation one possibility is to reduce the energy content of the ration, thereby increasing the protein (P) to energy (E) ratio (P/E). Another, is to increase the protein content of the diet. In practice, however, there are difficulties in reducing the energy content of the ration without reducing the protein, mineral and vitamin contents. It is easier to increase the protein content of the diet by some form of supplementation. The problem is compounded by the fact that ruminant livestock in the tropics are usually expected to grow and reproduce on feeds high in fibre and low in available energy, protein, vitamin and mineral content. Readers seeking further information on this subject should consult National Research Council (1981), Butterworth (1985) and McDowell (1985).

Strategies for Feeding Ruminants on Low Nutrient Content Feeds.

In most tropical countries low protein content forages and crop residues are the most abundant and appropriate ruminant feeds. There are, however, as stated previously, limits to the use of conventional feeding standards in evaluating these feeds. Some reasons for these limitations are that:

- The rumen can be considered to be part of a two-tier digestive system in which consideration has to be given to the nutrition of the rumen microbes as well as to the nutrition of the animal, with the consequence that the efficiency of the system cannot be determined by analysis of the feeds.

• On some diets feed intake may have no relationship to digestibility, but be strongly influenced by supplementation.

• The energy value of the diet and efficiency utilization may be, to a large extent, determined by the relative balances of glucogenic energy, long-chain fatty acids and essential amino acids absorbed by the animal.

• The availability of amino acids for the animal cannot be determined from an analysis of the CP content of the feeds.

Strategies to improve the utilization of fibre-rich, low protein, roughages have been outlined by Preston (1995), based on his own investigational work and that of others.

If ruminants are considered to possess a two-tier digestive system, then in the rumen (first tier) large-scale synthesis of microbes (bacteria and protozoa) occurs, requiring for optimal efficiency a balanced supply of microbial nutrients. Rumen microbes transform dietary carbohydrates into volatile fatty acids (VFA), methane and carbon dioxide, with production of heat. In the abomasum and the small intestine (second tier) microbial nutrients from the rumen and digestible feed components that escaped rumen fermentation provide basic nutrients for the animal. The critical issue for the animal is the ratio of protein (of both microbial and dietary origin) to the energy yielding substrate or the P/E ratio expressed as g protein/MJ energy from the VFA available for metabolism. This ratio determines the efficiency of utilization of the diet and hence the level of productivity (Preston & Leng, 1987).

Efficiency in this two-tier digestive system depends upon:

(1) Providing a balanced supply of nutrients for the proper growth of the microbes in the rumen. This can best be assured by:

(a) an additional source of nitrogen; usually the most economic will be by providing the animal with access to urea-molasses blocks;

(b) a source of macro- and micro-mineral elements, that should exist in the forage but can also be assured by the feeding of small quantities of highly digestible, fresh green forage at the rate of 2 kg per 100 kg of animal;

(c) providing a maximum intake of fermentable carbohydrates; best assured by offering a free choice of the high fibre low protein content forage at least 50% in excess of requirements.

(2) Providing an adequate supply of *by-pass protein*, i.e. protein that is not degraded or only slightly degraded in the rumen. The extent to which supplemental protein escapes degradation in the rumen is influenced by how it has been processed and the rate of flow of fluid and small particles out of the rumen. Also by the presence of green forage. Some tropical protein feeds, such as tree forages, contain phenols and other substances that react with the proteins during the chewing of the cud, protecting them against rumen fermentation.

Thus the efficient utilization of high-fibre, low protein content roughages and by-product feeds by ruminants in the tropics depends upon the provision of supplementary sources of energy and protein and an adequate supply of a suitable by-pass protein.

Types of Feed Available

There are obviously many methods that could be used for the classification of animal feeds. One method used in practice is to classify them into groups according to the predominant nutrient or nutrients which each contains. A selection can then be made from feeds within any one group for availability and cost, and the most suitable feed from any one group can be used in a mixed ration. In practice, any food from one group can be substituted in a mixed ration for any other food within the same group without substantially altering the nutrient balance of the mixed feed. It would, however, be a mistake to assume that all feeds within a group possess exactly the same feeding value or that the same feed grown in different parts of the tropics will have exactly the same composition.

One suitable classification by feed group is as follows:

(1) *Succulents*. Feeds whose principal constituent is water. They may be subdivided into two major subgroups: green forages and root crops.

(2) *Roughages*. These feeds are characterized by their high CF content. Some feeds that can be classified as succulents when they are young would be classified as roughages when they are mature.

(3) *Concentrates*. The main characteristic of all concentrate feeds is that they contain relatively large quantities of a major food constituent. They may be subdivided into concentrates of plant or animal origin, and concentrates of plant origin may be divided into a further two groupsthose that are energy-rich and those with a high CP content.

(4) *Other feeds*. Some feeds cannot be easily classified in any of the three major groups. This fourth group includes new types of feed that are manufactured from inorganic or organic materials.

In compounding any specific ration the relative quantities of feed used from these different groups will vary according to the species or breed within the species of animal which is being fed, and in accordance with the animal's production. For instance, ruminant animals can utilize food from all groups, but they utilize succulents and roughages more efficiently than other livestock and it may sometimes be wasteful to feed concentrates to them. Non-ruminants require mainly concentrate feeds, as do highly productive milking cows. Some data on the nutrient context of representative feeds from each of the groups are shown in Table 3.13.

Succulents

This group includes growing and fresh plant materials such as forage, browse, roots, tubers and fruits. The water content of succulents is often high and in general ranges between 40 and 90%.

Forage and Browse

These are of major importance in the feeding of tropical ruminant livestock. In previous editions of this book the availability and utilization of forage and browse in the tropics were discussed. There are now, however, a number of publications that the reader requiring detailed information on this subject may consult. These include Bogdan (1977), Pratt & Gwynne (1977) and Humphreys (1987).

During their growth stage, which may be rather limited in the tropics, forages including pasture can often provide sufficient nutrients for the maintenance and possibly limited growth or milk production of ruminant livestock. Within forages, legumes usually possess higher CP, mineral and vitamin contents than grasses. Browse legumes often possess high CP, mineral and vitamin contents, though their digestibility may be somewhat less than that of forage legumes.

Other

Roots, tubers, plantains, bananas and other fruit are grown in large quantities in the monsoonal and wet tropics and are widely used as livestock feeds (Machin & Nyvold, 1992). Major root and tuber crops are cassava (*Manihot esculenta*), yams (*Dioscorea* spp.), sweet potato (*Ipomoea batatus*), taro (*Colocasia esculenta*) and arrowroots (*Maranta arundinacea, Canna edulis*). Breadfruit (*Artocarpus altilis*) has approximately the same feed value as the typical root crop while plantains (*Musa paradisiaca*) and bananas (*Musa sapientum*) possess slightly less feed value. The energy content of the dry matter of root crops is high, the water content varies and the CP, mineral and vitamin contents are generally low. Fruits generally possess a high water content and often relatively high vitamin and mineral contents.

Silages made from succulents will vary in nutritive value according to what feed was originally ensiled. The feeding value will always be

Table 3.13 The proximate analyses of some representative feedstuffs. (*Sources*: Composite data from Morrison, 1959 and McDowell *et al*., 1974.)

Group	Feedstuff	On dry matter basis: Dry matter (%)	Ash (%)	Crude fibre (%)	Ether extract (%)	Nitrogen-free extractive (%)	Crude protein (%)	Total digestible nutrients (%)	Calcium (%)	Phosphorus (%)
Succulents	*Panicum maximum* (guinea); 1528 days' growth	19.4	14.3	30.9	3.4	39.2	12.2	10.2	0.86	0.36
	Centrosema pubescens (centro)	24.2	8.3	31.0	3.9	35.7	21.1	14.9	1.30	0.31
	Manihot esculenta (cassava) roots	37.1	3.0	4.3	0.9	88.3	3.5	31.6	0.26	0.16
Roughages	*Cynodon dactylon* (Bermuda) hay	87.4	10.2	32.0	5.3	39.2	13.2	43.2	0.75	0.23
	Oryza sativa (rice) straw	89.0	17.7	35.7	2.4	38.7	5.4	37.7	0.29	0.36
Concentrates *Plant origin*										
Energy rich	*Oryza sativa* (paddy)	89.4	7.9	9.5	3.8	68.5	10.2	51.9	0.41	0.50
	Zea mays (maize) cracked grain	87.2	3.3	3.0	3.7	79.5	10.5	66.5	0.20	0.22
	Gossypium spp. (cotton) seed	90.2	5.2	14.6	22.6	36.5	20.8	53.9		
Protein rich	Coconut meal (solvent extracted)	91.1	6.6	13.3	2.4	47.4	21.4	68.6	0.21	0.64
	Sesame meal	93.7	11.6	6.2	9.0	23.6	43.3	71.3	2.02	1.61
	Soybean meal (expeller extracted)	91.0	6.2	5.9	4.9	30.0	44.0	77.9	0.27	0.63
Animal origin	White fish meal	90.7	20.5	0.2	6.8	0.3	62.9	72.4	6.76	3.69
	Meat and bone meal	93.7	28.1	2.2	10.6	3.1	49.7	65.3	10.67	5.27
	Dried skim-milk	93.9	8.0	0.6	1.1	51.1	33.1	79.8	1.28	1.04
Other	Cane molasses	73.4	8.6	0.0	0.0	61.7	3.0	53.7	0.66	0.08
	Wet brewers' grain	23.7	1.0	3.6	1.6	11.8	5.7	16.1	0.07	0.12

lower than the fresh material due to wastage during the ensiling process.

Roughages

It is probable that a majority of ruminant livestock in the tropics subsist on roughage for a major part of the year.

Forage Roughage

This includes hay, standing hay and artificially dried forage. Good hay made at the correct stage of growth can be an excellent maintenance roughage feed. Unfortunately, little good hay is made in the tropics. Most of the hay that animals consume is 'standing hay' or forage that has matured *in situ*. Under favourable circumstances, such as occur in the sahelian climatic zone of Africa and in some regions of the savanna, standing hay can be a medium-quality roughage. Normally, however, it is fully matured forage with a very low feeding value, containing a high content of an indigestible mixture of cellulose and lignin.

Artificially dried forage may be classified as a roughage or as a concentrate feed, depending on the nutrient content of the original forage and the stage at which it was dried.

Straws and Haulm

The straws of the cereal crops grown in the tropics such as rice (*Oryza sativa*), maize (*Zea mays*), sorghum (*Sorghum vulgare*) and millet (*Pennisetum typhoideum*) are almost universally used for feeding purposes, as are the haulms of legume crops such as groundnut (*Arachis hypogaea*) and the dried stalk materials of such crops as sesame (*Sesamum indicum*) and cotton (*Gossypium* spp.). These roughages generally posses a low feeding value, but livestock grazing them also have access to the weeds in the stubbles and these improve the overall feed value of straws and haulms. Legume straws or haulms possess a higher feeding value than other straws.

There are other roughage feeds available at specific locations in the tropics such as the waste materials from oil palm processing plants, sisal waste, pineapple waste, bagasse, cocoa pods, coffee hulls, etc. The feeding value of these materials varies, but it is usually low.

As roughages are such an important feed source for livestock in the tropics there is a major interest in improving their digestibility and hence their feeding values. The methods being used are:

• Physical treatment such as chaffing and milling.

• Chemical treatment that may include enhancement.

• Biological treatment using organisms that can degrade lignin or break the bonds between lignin and cellulose in plant cell walls.

• An appropriate combination of two or all of these methods.

Many countries in the tropics, particularly in South and Southeast Asia, are engaged in research on this subject. Further information may be obtained by interested readers from publications by Jackson (1978), Doyle *et al*. (1986), Ibrahim & Schiere (1986) and Preston & Nuwanyakpa (1986).

Concentrates

There are, of course, a wide variety of concentrate feeds produced in the tropics, but those that are normally economic to feed are usually the by-products of crop or animal production.

Concentrates of Plant Origin.

These include both energy-rich and protein-rich feeds.

Energy-Rich Feeds

The major group are the cerealsrice, maize, sorghum and millet. Their energy contents are high, CP content medium and CF content low. Their mineral content varies but is often unbalanced. As they are normally staple human foods in the countries in which they are grown it is unusual for them to be used as animal feeds except in restricted quantities in specific regions. If a surplus of cereals is available it is usually most economic to feed it to non-ruminants and in particular to poultry.

Other energy-rich concentrates are sugar and dried roots such as dried cassava, a major product in some countries in Southeast Asia where it is produced for export to Europe. Sugar is not normally fed to livestock, but when sugar prices are depressed it is an excellent feed to incorporate in the ration of young pigs.

Oil seeds, from which many of the protein-rich cakes are manufactured, are high energy content feeds, principally on account of their high fat content. They are not usually used for feeding purposes, the exception being cotton seed.

Protein-Rich Feeds

Grain legumes, like cereals, are normally used for human consumption, but where there is a surplus they can be fed to animals. The quality of their protein is relatively high.

Oil cakes and meals are the most common protein-rich concentrates. They include groundnut, soybean, sesame, palm kernel, cotton seed, rubber seed and coconut. Usually they have a relatively high energy content and a CP content that varies from 15 to 45%. Their feeding value depends partly on the amount and quality of the protein that they contain, partly on the amount of fibre and other inedible material retained in the cake after processing of the original plant material and partly on whether they contain any toxic materials after processing. Those cakes processed by primitive methods will contain quite a high oil contentsometimes as much as 10%. Their mineral content varies considerably, but they are often rich in phosphorus. Their vitamin content will be minimal on account of the processing. Some oil seeds, such as cotton and rubber, contain compounds that are toxic to non-ruminants. Cotton seeds contain an aromatic aldehyde known as gossypol, toxic to non-ruminants at low levels, but inactivated by special processing. Rubber seed contains a cyanogenetic glucoside known as linamarin and an enzyme known as limase which hydrolyses the glucoside. The raw cake can therefore be toxic and should be boiled or processed in some other way before feeding.

Concentrates of Animal Origin

These include the by-products of meat animal processing such as meat meal, meat and bone meal and blood meal, the by-products of fish processing such as fishmeal and shrimp meal, and the by-products of milk processing such as skim-milk powder, whey and buttermilk. They are characterized by the relatively large quantities of high-quality protein that they contain and by a high mineral content. The vitamin content of some of these feeds may also be considerable.

In general these feeds are not freely available in the tropics as most animal and fish offals are consumed by the human population and there is insufficient milk available for processing. However, in a few tropical countries there is a waste of these by-products, either because suitable processing plants are unavailable, existing processing plants are inefficient or on account of local ignorance of the value of the by-products.

Others:
Including Unconventional Feeds

These include by-product feeds such as sugar and citrus molasses, brewery and distillery by-products like brewers' grains and fermented feeds. The latter are of some importance in certain regions of Southeast Asia.

There is at present in industrialized countries a very considerable interest in new sources of feed. Many of these 'new' feeds could be of value in the tropics.

The possibility now exists for plant breeders to breed plants that are more nutritious. An example is the breeding of high-lysine varieties of maize. Obviously this idea could be of the greatest interest in the tropics where new, highly nutritious, varieties of all types of crops are urgently required.

The use of waste faecal material for the culturing of chlorella is at present practised only in some countries in Asia, such as Taiwan. The chlorella can then be used as a protein concentrate for pig feeding. Animal manures can also be used for feeding purposes. Interested readers should consult BSAP (1980) and Muller (1980).

Possibilities for the processing and utilization of leaf protein or grass juice containing leaf protein are promising in the humid tropics. The leaf protein concentrate with a CP of 6070% could be used for non-ruminant feeding while the discarded material could be used as a roughage for the feeding of ruminants. Readers with a

particular interest in this unconventional feed should consult Pirie (1987).

The production of single-cell protein concentrates using specific yeasts from waste carbohydrate materials such as the contaminated flour from cereal processing mills or from paraffins or gas oil is slowly developing. The process that uses waste flour as a substrate produces a high-quality protein suitable for human consumption while that which uses paraffins or gas oil produces a 6370% CP concentrate suitable for feeding to pigs, poultry and calves. In tropical countries where there are by-product carbohydrate wastes or plentiful supplies of natural gas these new processes could be of value.

In the Philippines an edible yeast has been successfully cultured on coconut water, a product that is normally wasted at copra processing plants. A protein of bacterial origin is on the market in the United Kingdom.

Storage of Feeds

The storage of all feeds is a very considerable problem in the tropics. They should be stored in dry, vermin-proof accommodation, in which air can circulate freely and where ambient temperatures can be kept as low as possible. Concentrate feed stores should be regularly treated with an insecticide. The normal method of treatment is fumigation. Protein concentrates are particularly liable to deterioration. The fats in them may undergo oxidative changes and become rancid, making the feed unpalatable. Fungal infection of some concentrate feeds can lead to the feed becoming toxic. This is particularly likely to occur in hot, humid climates.

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4
Reproduction and Breeding

Introduction.

Although some of the very first animal-breeding practices must have been initiated when Neolithic man domesticated animals, the major part of modern animal-breeding practice has developed in the temperate zone during the last two centuries.

In some temperate-zone countries, particularly in northwest Europe, the overall environment for livestock had been improved to such an extent by the beginning of the nineteenth century that attention could be directed towards the breeding of improved types of livestock that could take economic advantage of this situation. In addition, in northwest Europe the most adverse effects of climate on livestock could be avoided by the provision of adequate housing. As a consequence, during the nineteenth century spectacular advances were made in livestock breeding, particularly in the United Kingdom. However, these advances, although based on acute observation and limited records, were still very much the result of trial and error, as little was known of modern genetic theory.

The science of genetics, based on Mendelian theories of inheritance, began to gain general recognition at the beginning of the twentieth century, and during the last 60 years the application of genetic principles, combined with new knowledge gained on the physiology of reproduction, has revolutionized animal-breeding practices. The pace of change is still accelerating, with the advent of new knowledge on the molecular structure of DNA (deoxyribonucleic acid) and the location of genes on chromosomes, making possible the use of genetic engineering or recombinant DNA technology in animal breeding.

These practices are slowly being applied in tropical countries. In the latter, few of the livestock-owning peoples have in the past developed rules or customs concerned with the better breeding of their animals. The majority have allowed their livestock to breed more or less haphazardly and the results have been accepted as a matter of fate and therefore inevitable. Nevertheless, a number of factors have contributed to the evolution of a multiplicity of different breeds of tropical livestock. In the first place the original domestication of many species probably occurred in the tropics and/or subtropics. Secondly, the large-scale movement of some livestock-owning peoples within the EuroAsianAfrican land mass, followed by periods of isolation due to intermittent warfare and/or the natural hazards of communication of small groups of people in large land areas, meant that livestock were moved into isolated areas where they naturally developed over a long period characteristics that fitted them to their new environment. Some peoples probably also bred their livestock for specific features, and originally this action may have had magico-religious connotations. One example of adaptation is that the *Bos taurus* breeds of Hamitic Longhorn cattle that were first taken by migratory people from Western Asia to the tsetse-fly infested forest regions of West Africa, perhaps some 5000 years ago, have developed a degree of tolerance to trypanosomosis that is certainly not possessed by any other major cattle breed originating from Western Asia. Not only have both the N'Dama and Dwarf Shorthorn breeds developed this tolerance, but the tolerance of the N'Dama cattle, which were the first to arrive in West Africa, is more developed than that of the Dwarf Shorthorn cattle. On the other hand, there must have been deliberate selection by man in East Africa for very large horns within cattle of the Ankole breed.

Efforts to improve the productivity of livestock in the tropics have moved in a cyclic manner ever since the sixteenth century. At that time, when Europeans first discovered and then colonized the Americas, they imported their unimproved domestic livestock with them. These livestock thrived in the temperate but not in the tropical regions of the Americas. However, some of the breeds imported into the tropical regions did gradually acclimatize. One example is the criollo cattle of tropical Central and South America. However, the parallel importation of European livestock into Africa and Asia was almost totally unsuccessful except in some tropical islands. Later, with the advent of a large-scale slave trade between Africa and the Americas some African livestock such as N'Dama cattle and Dwarf Forest sheep and goats were imported into the Americas. These livestock were crossed with imported temperate-type livestock and now form the basis for some modern American breeds such as the Senepot (syn. Nelthropp) cattle and the Black Bellied Barbados sheep of the West Indies and several sheep breeds in northeast Brazil. In the eighteenth and nineteenth centuries there were also considerable importations of tropical livestock from Asia into Europe, an important example being the Siamese and Chinese pigs which have contributed characteristics to modern British pig breeds (see Chapter 14).

During the latter part of the nineteenth century, as it began to be realized that many of the original importations of temperate-type livestock into the tropics were not flourishing, there was a considerable importation of Asian cattle into tropical and subtropical America.

Improvements in the breeding of European and North American livestock, with the realization that the productivity of the new breeds far surpassed the productivity of any indigenous tropical breeds, led at the end of the nineteenth and at the beginning of the twentieth century to a new cycle of importation of temperate-type livestock into the tropics. The failure of these importations was immediately apparent as by this time governments were monitoring importations and beginning to keep records. It was ultimately realized that until such time as epizootic disease was controlled and nutrition and management improved, the possibilities for the successful introduction of highly productive temperate-type livestock into the tropics were poor. A major effort was then made to identify tropical breeds and to initiate selection within them. The result of these efforts has often been disappointing and as a consequence another major effort is now being made to introduce productive, temperate-type livestock into the tropics; primarily for crossbreeding purposes. The possibilities for success are now much greater than they were in the past, as we possess more knowledge of the characteristics of tropical and temperate-type livestock and we are better able to control and modify the tropical environment.

In order to promote a rapid improvement in the productivity of tropical livestock we must first understand the basic facts of reproduction and the inheritance of characteristics and be able to apply suitable animal-breeding and other practices that have been developed in the temperate zone.

The development of the livestock industry in the tropics depends upon improvements on a 'broad front', but it is also important that development priorities should be established. In areas where epizootic disease is still prevalent it is obvious that disease control must be accorded some priority. Elsewhereand in those regions where the major epizootics have already been brought under controlimproved feeding and management should be accorded priority. It is axiomatic that it is useless to improve the genetic merit of livestock if environmental factors remain unimproved, and that the upgrading of livestock must be accompanied by the upgrading of management and by improvements in the overall environment. On the other hand, improvements in management and in the environment should not be allowed to outpace improvements in the genetic merit of the animals managed within that environment. It is just as wasteful to provide an environment that cannot be fully exploited on account of the low genetic merit of the livestock used, as it is to provide animals of high genetic merit for a poor environment.

The Reproductive Cycle

The reproductive cycle begins when the *ovum* or egg of the female is fertilized by the *spermatozoa* or sperm of the male and it ends at parturition.

Diagrammatic representations of the male and female reproductive organs of cattle are shown in Fig. 4.1 ((a) and (b)). Those of other domestic mammals are somewhat similar but there are differences in those of domestic birds and some other domestic species.

Male reproductive cells or sperm differ markedly from other body cells in that they possess a tail-like structure and are mobile. In mammals, sperm are produced in a testis, two of which are encased in and protected by a *scrotum*, to form testicles that are usually placed outside the body cavity. This is not necessarily the case in other domestic species. The scrotum usually possesses a muscular attachment that allows a male to raise or lower his testicles. In bulls, during hot weather the testicles are lowered away from the body, presumably in an attempt to reduce their internal temperature, whilst in cold weather the scrotum contracts.

Sperm are produced in vast number by the process of *spermatogenesis* in the epithelium of the convoluted *seminiferous tubules* of the testes and are stored in a retaining reservoir known as the *ducius epididymis* (Fig. 4.1(a)). They mature and acquire full fertilizing capacity during epididymal storage and transit, the time of which varies between species. Although spermatogenesis is continuous, beyond specific periods the sperm may lose viability. In the case of bulls this period is about 2 months.

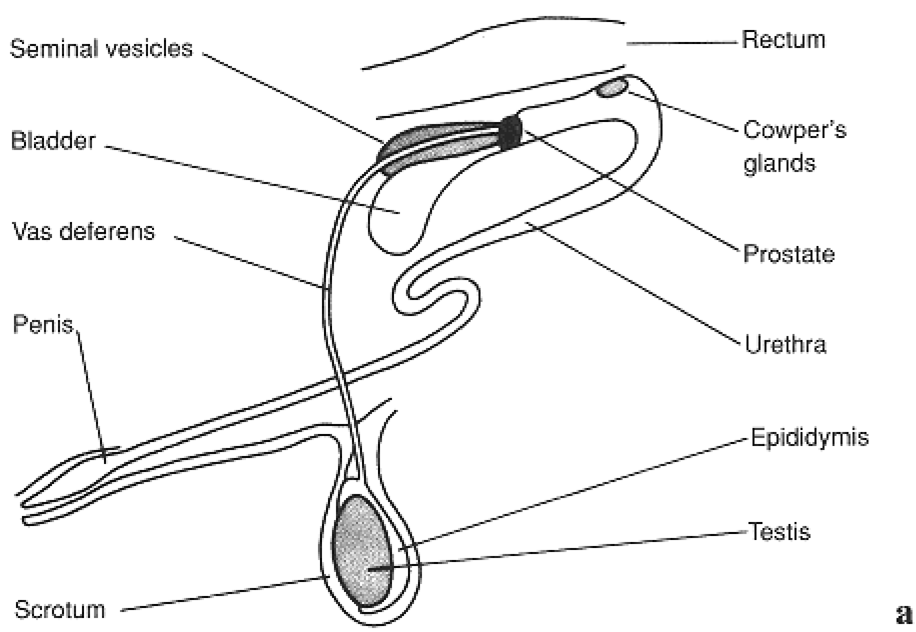
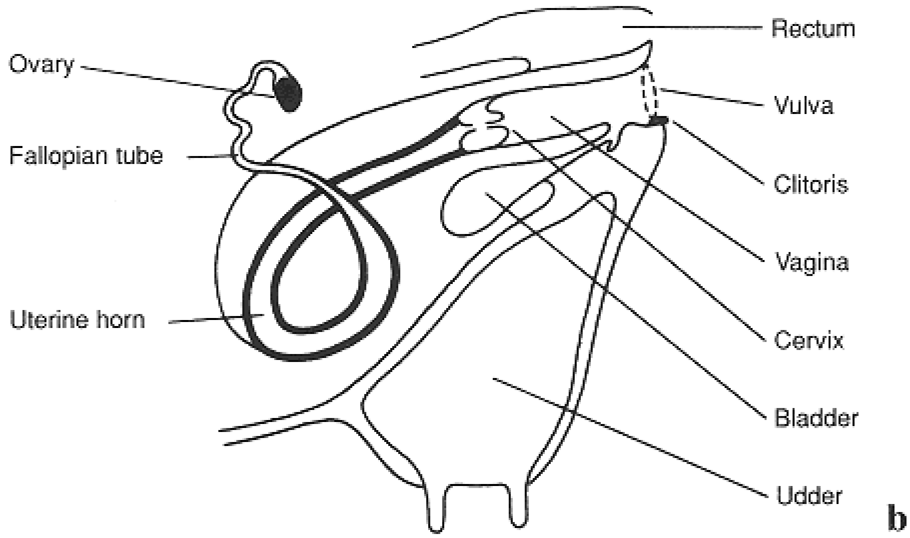


Fig. 4.1
(a) Diagrammatic representation of the male reproductive organs of cattle.



(b) Diagrammatic representation of the female reproductive organs of cattle.

Spermatogenesis can be affected by high ambient temperature and other external factors.

The hormone that activates the sex instinct and sexual activities of males is produced in the testes. There are also various glands accessory to the testes that provide the fluid medium in which sperm are conveyed from the male into the genital organs of the female during the act of copulation at mating. The mixture of fluid medium and sperm is known as *semen*, the volume of which produced at any one time, varies considerably between species, as does its average sperm content (Table 4.1). The period during which sperm retain viability within the female genital tract also varies from species to species. In the cow the average duration is 30 hours, in the ewe 2224 hours, and in the sow up to 35 hours. In some

Table 4.1 Data on the semen of some domestic livestock species.

Species	Volume of male ejaculate (ml)		Average sperm content of semen
	Range	Average	(million/ml)
Buffaloes	2.013.0	3.0	900
Cattle	2.010.0	5.0	1000
Goats	0.13.5	0.7	2700
Sheep	0.23.0	1.0	2500
Pigs	50.0400.0	250.0	125
Fowls	0.11.0	0.2	4000

birds viability may be retained for as long as 2 or 3 weeks.

In most domestic species mating can be accomplished only when the female is at a specific stage in her sexual or oestrous cycle. Camels and llamoids are an exception, as in their case copulation induces *ovulation* (see Chapters 11 and 12).

Semen is deposited in the female genital tract during mating, the main deposition site varying from species to species. In cows (Fig. 4.1(b)) and ewes it is usually in the lower part of the vagina, while in sows and mares it is in the cervical canal. After deposition sperm from the semen moves through the cervix into the uterus and on into one of the *Fallopian tubes*, where fertilization may take place if an egg is present. Movement of sperm from the deposition site to the Fallopian tube is usually accomplished in 215 minutes, partly by its own power and partly by the aid of rythmic contractions of the vagina, cervix and uterus. Only a fraction of the sperm ejaculated into the female tract reaches the egg. Within the female tract the sperm undergo a preparative process known as *capacitation*. Several sperm probably play some part in penetrating the outer layers of the egg, but only one fuses with it. Penetration is aided by the exudation of enzymes that help to break down the cell walls of the egg. Immediately on fusion of one spermatozoa with the egg the latter releases chemical substances that prevent penetration and fusion with other sperm.

Eggs are produced in the ovaries of the female (Fig. 4.1(b)) and are released alternately from one or the other. The ovaries also produce hormones that activate and regulate the sexual activities of the female. Ovaries are usually much smaller than male testes; for example a cow's ovary is about 2.5 cm in diameter and the eggs it produces are microscopic. Eggs are produced in the ovary's outer layer that is composed of germinal epithelium. Within this tissue specialized groups of cells known as *primary follicles* are the potential source of eggs. At sexual maturity, and at specific intervals thereafter, one or more of the primary follicles rapidly mature within a thin fibrous, capsulated structure known as a *Graafian follicle*. In cows these follicles are of a sufficient size to be visible to the naked eye. As the follicle matures the walls become thinner and thinner and finally rupture at the surface of the ovary, releasing an egg into the fibrillated, wide-mouthed end of the Fallopian tube. This process is known as *ovulation*. In the Fallopian tube the egg is held for a time, usually several hours, in a coagulated mass which is formed from the viscous fluid that is released from the follicle at the same time as the egg. After a period, that varies from species to species but is usually a few hours, the coagulated fluid reliquefies, releasing the egg and allowing it to move along the Fallopian tube towards the uterus. It is at this stage that fertilization of the egg by a sperm can take place.

After ovulation the cavity in the empty follicle on the surface of a mammalian ovary is variously known as the *yellow body* or the *corpus luteum*. Hormones are secreted by this structure to ensure the continuation of gestation and the suspension of further ovulation until after parturition. Should the egg fail to be fertilized it loses its viability within a few hours, the yellow body disappears, the balance of hormones within the female's body changes and the oestrous cycle recommences.

Factors Affecting the Oestrous Cycle

Although the oestrous cycle of the female is mainly governed by hormones that are secreted internally, there are other factors that exert a considerable influence on it, either directly or indirectly. The extent of their influence varies both between and within species and breeds.

Apart from the abnormality of disease, the most important factors affecting the oestrous cycle appear to be the plane of nutrition, the length of daylight and ambient temperature.

Nutrition

The inadequately fed female animal grows slowly and her sexual maturity, and hence the onset of her oestrous cycle, is delayed. Very large numbers of tropical cattle have to subsist on a low level of nutrient intake for long periods during the year. As a consequence the first effective heat periods of heifers are often delayed until they are 2 years or older. On the other hand, in some species such as sheep, an abundance of feed during or just before the normal breeding season often increases fertility, as more than one egg is liberated at ovulation with resultant multiple births.

Certain individual forage plants can also affect the sexual cycle of the livestock that consume them. For example, there are grasses and legumes that at certain stages of growth contain substances comparable in chemical composition to the sex hormones produced by animals. The consumption of these plants may have either a beneficial or an adverse effect, according to the time of the year and the amount consumed. In Australia, Merino ewes consuming considerable quantities of a subterranean clover (*Trifolium subterraneum* var. *Dwalganup*) exhibit infertility and difficulties in gestation and parturition. Pigs fed large quantities of the legume *Leucaena leucocephala* lose hair and often become infertile.

Length of Daylight

Changes in the length of daylight may affect the sexual cycle of all domestic livestock, but the effect is only of major importance for sheep, goats and poultry.

In the temperate zones the breeding season of sheep is associated with a shortening day. As a consequence ewes transferred from the northern hemisphere temperate zone to the southern change the months in which they breed. In the tropics, where the length of daylight varies little throughout the year, most breeds of sheep reproduce at any season, although there may still be some seasonal variation in the intensity of breeding. Rams transferred from the temperate to the tropical regions of Australia are usually infertile for the first year after the transfer. Male goats transferred from the temperate region of Australia to Fiji were reported to behave in a similar manner.

The effect of light periodicity on poultry has been used commercially to increase egg production. This can be raised appreciably by slowly increasing the length of exposure of the birds to natural or artificial light.

Ambient Temperature

There is considerable experimental evidence that high ambient temperatures directly affect the sexual cycle of female livestock (see Chapter 1), the libido of males and the viability of their sperm.

Managerial Considerations

Since, with the exception of the Camelidae, ovulation occurs at a definite time, measurable in hours after the onset of heat and that in all mammalian species the egg and the sperm are relatively short-lived, it is very important that mating should be planned so as to coincide with ovulation. As far as is practicable mating should take

place about the same timeor somewhat beforeoevulation occurs so that the sperm will have the maximum chance of meeting with an egg that is passing down the Fallopian tube. Thus in order to properly plan matings it is important to know the length of the heat period, the duration of heat and the time of ovulation. These vary from species to species. Some details of average data for various species are shown in Table 4.2. The first occurrence of heat is determined mainly by environmental factors, but within the same environment there is considerable individual animal and breed variation.

The occurrence of heat is evident in most species by some form of restlessness on the part of the female and by her seeking out a male. In some species, particularly the pig, there is a slight relaxation of the external genitalia. However, even within species there is a very wide variation in the manner in which females exhibit the onset of heat. In some females heat is easy to detect and in others it is very difficult. For example, it is well known that heat detection can be very difficult in some breeds of *Bos indicus* cattle while it is particularly easy in the Bali breed of *Bos (bibos)* cattle. What is certain is that the easiest manner of finding out if a female is in heat is to see if she will accept a male.

Fertilization and Gestation

When a female accepts a male and he copulates and ejaculates, millions of sperm are deposited in her reproductive tract. Only a portion of these, however, reach the extremity of the uterus and only then if the genital passages are relaxed, are free from inflammation and the secretions in the tract are chemically and physically appropriate. Eventually only one sperm will fuse with the egg. Which one of the many will accomplish this feat is probably a matter of pure chance. That is not to say that only one sperm is necessary for fertilization to take place. On the contrary, it has been well established that there must be a certain concentration of sperm at the site of fertilization if one of them is to be effective.

The process is somewhat different in the case of birds. As no yellow body replaces the ruptured follicle in the ovary and therefore no hormone is excreted to inhibit further ovulation, an egg can be released each day. In the case of the hen, the cock's sperm accumulates towards the end of her Fallopian tube and each egg is fertilized as it moves along the tube.

The fusion of one sperm from the male and the single egg of the female constitutes fertilization and is the only physical link between one generation and another, that is to say that the genetical make-up of the male and the female are combined at the moment of fusion to produce a fertilized egg, called a *zygote*. Shortly after fertilization this zygote begins to divide. The first division is generally completed within 24 hours. As the result of repeated cell divisions a small ball-like cluster of cells called a *morula* is formed. Further division and growth leads to the

Table 4.2 Average length of oestrous cycle, duration of heat and time of ovulation of some domestic livestock species.

Species	Oestrous cycle (days)		Duration of heat (hours)		Time of ovulation (hours)	
	Average	Range	Average	Range	Average	Range
Buffaloes	21	very variable	36	12120	very variable	524 after end of oestrus
Cattle	21	1626	18a	1422	11	222 after end of oestrus
Goats	19	1821	28b	2472		1236 after onset of oestrus
Sheep	17	1421	26	2448		24 before end of oestrus
Pigs	21	1630	48	4065	36	1847 after onset of oestrus

a*Bos indicus* cattle often exhibit shorter heat periods as do *B. taurus* milking cattle managed in the tropics.
b Considerably shorter in some tropical breeds.

formation of a hollow ball of cells known as a *blastocyst*. At this stage the blastocyst is no longer in the Fallopian tube but in the uterus where cell differentiation takes place. One side becomes an inner cell mass that will become the embryo whilst the surrounding cells, collectively called the *trophoblast*, make contact with and adhere to the epithelium of the uterine mucosa. The uterine mucosa then surrounds the blastocyst, which is thus implanted. Up to this time, nutrition of the dividing cells is provided for by 'uterine milk', a secretion of the uterine cells.

At implantation the embryonic membranes develop. Those of the cow are shown in Fig. 4.2. Three membranes envelop the embryo; the outer *chorion*, the outer layer of the *allantois* which is joined with the chorion to form the *allanto-chorion* and the inner *amnion* (enclosing the amniotic sac in which the embryo develops). The amnion coupled with the inner layer of the allantois forms the *allanto-amnion*. The yolk sac is part of the primitive mid-gut of the developing embryo, but in mammals it is a vestigial structure as it contains no stored food materials as it does in birds. The allantois and the amnion are filled with fluid.

Implantation is a gradual process. It occurs at about 56, 35, 1518 and 1012 days after conception in the mare, cow, ewe and sow, respectively. In general, the shorter the gestation period the more quickly implantation occurs.

Implantation occurs so that there can be an exchange of substances between the maternal and embryonic tissues. This exchange takes place through a composite structure known as the *placenta*. It consists of the allanto-chorion, which is the embryonic part, and the mucous membrane of the uterus, which is the maternal part. Different species possess different types of placenta. The placenta of the pig is diffuse, the allanto-chorion making direct contact with the uterine mucosa, while in ruminant species the exchange of materials between the mother and the fetus occurs through 'button'-type structures known as *cotyledons*.

The development of the fetus appears to be very slow during the early stages of gestation, but the pace gradually quickens. In *Bos taurus* cattle, for example, the average 45-day-old fetus weighs approximately 85 g, while at 90 days it will weigh about 1.0 kg and at 200 days approximately 10 kg.

There is considerable variation in the length of the gestation period between species and some variation between breeds and types within species (Table 4.3).

At parturition the placenta is normally evacuated from the uterus after the young animal is born.

Influence of Hormones on Reproduction

Hormones have a role at all stages in the reproductive cycle. They are chemical substances, synthesized in specific tissues, that are secreted

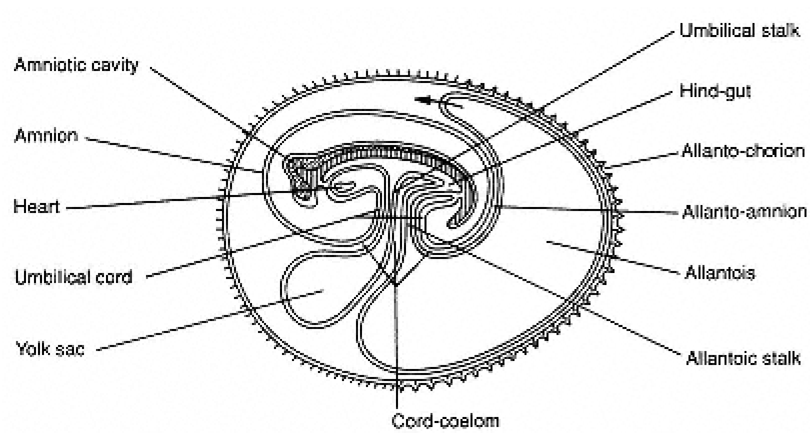


Fig. 4.2
Schematic illustration of the fetus and fetal membranes in the cow about 27 days after fertilization of the egg.
(Source: Johansson & Rendel, 1968.)

Table 4.3 Gestation periods of some domestic livestock species.

Species	Type	Breed	Gestation period (days) Average	Range
Buffaloes	River	Murrah	308	302313
		Egyptian	317	313319
	Swamp		332	301343
Camels	Dromedary		383	360390
Cattle	Temperate		280	273289
		Angus		273282
		Brown Swiss	289	
		Charolais	289	
		Friesian	279	
		Hereford		283286
		Jersey		278280
	Tropical			284288
Goats	Temperate	Saanen	154	
	Tropical		146	145148
Llamoids	Alpaca	Huacaya	342	
		Surti	345	
	Llama		330	
Pigs	Temperate		114	110117
Sheep	Temperate	Dorset Horn		140148
		Merino		148152
	Tropical			140160

directly into the blood and circulated throughout the body where they affect particular tissues, causing functional changes.

The orchestration or integration of hormone production within the reproductive cycle is conducted from a site in the brain of the animal known as the *hypothalamus* (Fig.4.3). This controls the pituitary gland, which produces the gonadotrophic hormones, including the follicle-stimulating hormone (FSH), the luteinizing hormone (LH) and the luteotrophic hormone (LTH) which stimulates the yellow body in the follicle to produce the hormone *progesterone*. The pituitary also produces several other hormones which regulate other specific bodily functions not directly concerned with the reproductive cycle such as the growth hormone (GH) and the thyrotropic hormone (TSH), etc.

The major hormones concerned in the reproductive cycle are as follows.

Follicle-Stimulating Hormone (FSH).

The main functions of FSH in the female are to stimulate follicular growth in the ovaries, to stimulate the secretion of oestrogen by the ovaries and to control the maturation of the egg. In the male, FSH initiates the growth of the testes and induces the production of sperm.

Luteinizing Hormone (LH)

In the female LH controls the rupturing of the follicle, thus initiating ovulation. It is also re-

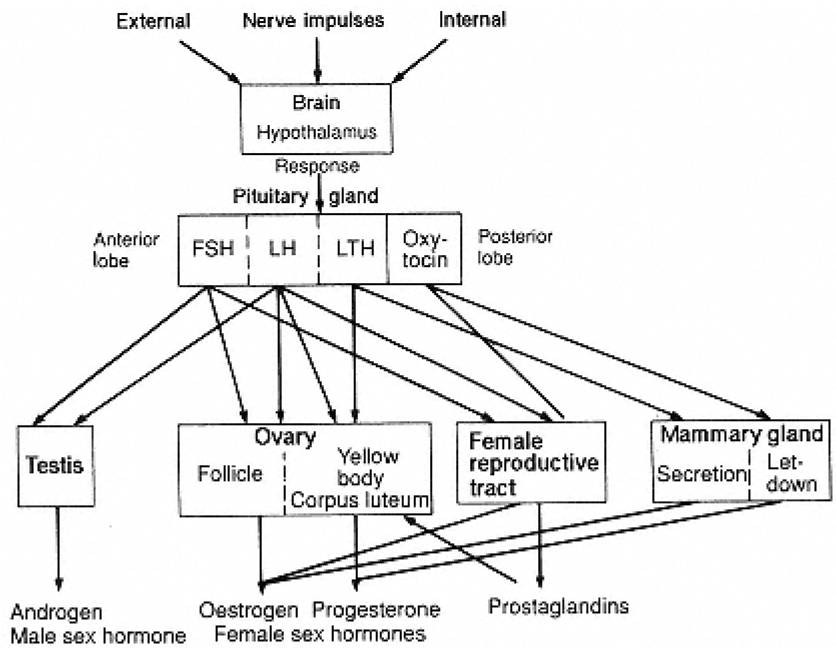


Fig. 4.3
Simplified schematic representation of the endocrine glands concerned with reproduction.

sponsible for the production of the *corpus luteum* (yellow body) in the ruptured follicle. In the male LH stimulates the production in the testes of *androgen*, the male sex hormone.

Luteotrophic Hormone (LTH)

This hormone controls the production, by the yellow body in the ovarian follicle, of progesterone. It is also concerned, in conjunction with other hormones, with mammary gland development and the initiation of milk secretion.

Sex Hormones

The ovaries of the female and the testes of the male serve a dual role. They not only produce the cells or *gametes* that transmit characteristics from one generation to the next, but also female (oestrogens and progestogens) and male (androgens) sex hormones. Production of the female sex hormones ebb and flow; preparing the female for mating and her reproductive tract for pregnancy and maintaining secondary sexual features.

Oestrogen

This is synthesized by cells surrounding the ovarian follicles while they are developing under the influence of FSH. It circulates at the highest level during oestrus, being responsible for bringing the female to an excitable state during heat, so that she will accept the male. One effect on the vagina is to increase the secretion of mucus.

Progesterone

Primary production is in the yellow body in the ovarian follicle, but some is also produced by the placenta during pregnancy. It prepares the uterus for implantation of the fertilized egg and generally ensures the normal course of pregnancy. Together with oestrogen it affects the mammary glands, preparing them for the end of pregnancy when they will be required to secrete milk.

Androgens

A major androgen, testosterone, is synthesized by the interstitial cells, located in clusters between the seminiferous tubules of the testes. It stimulates and supports spermatogenesis and is responsible for the development of all male secondary sexual characteristics and the stimulation of libido.

Other Hormones Affecting Reproduction

Oxytocin

This is a neurohypophyseal hormone that causes contraction of the smooth muscle in the uterus and of myoepithelial cells in the mammary glands. In addition, it has recently been shown to also be a neurotransmitter with important effects that include the initiation of parental and sexual behaviour.

The synthesis and release of it from the posterior lobe of the pituitary can be affected by neural stimuli. Its effect on the contractability of uterine muscle facilitates the movement of spermatozoa along the female tract following coitus and the expulsion of the young from the uterus at birth. In mammary glands myoepithelial contraction, stimulated by the release of oxytocin into the bloodstream is the physiological basis for the let-down process in milking (see Chapter 7).

Melatonin.

The pineal gland, located in the brain, is involved through its action and pattern of melatonin secretion, in conveying photoperiodic information to the brain. In both long- and short-day breeding ruminant animals, melatonin secretion is restricted during daylight, though in periods of darkness there are significantly elevated secretion levels.

Melatonin secretion does not generate reproductive cycles but it entrains endogenous reproductive rhythms to lightdark cycles (D'Occhio & Suttie, 1992). At present this role is poorly understood. Sheep and goats, for example, possess similar diurnal rhythms of melatonin secretion but differ in seasonality and cattle only show a very limited response to melatonin. In the temperate zone melatonin is being used to induce out-of-season lambing. Any role that it may ultimately play in tropical animal husbandry is, as yet, unclear.

Manipulation of Reproductive Processes

The role of hormones in reproduction is obviously important; they may be used to increase productivity and/or to treat reproductive disorders. There is increasing knowledge and experience as to the methods by which reproductive processes may be manipulated. These include: synchronization of oestrus, pregnancy testing, multiple ovulation, recipient-donor oestrus cycle synchrony, deep freezing embryos, *in vitro* production of embryos, multiplication of embryos and possibilities for sex determination in mammalian livestock and embryos. Some, but not necessarily all, of these techniques may be useful in tropical livestock husbandry.

Synchronization of Oestrus

There has been considerable experimental work on the synchronization of oestrus in groups of cattle, sheep, goats and pigs and practical methods of synchronization in cattle have been evolved using two doses of a hormone (prostaglandin analogue) at 1011 day intervals. In well managed herds large-scale synchronization of oestrus followed by fixed time artificial insemination (AI) can be expected to produce calving rates similar to those obtained in herds using AI at detected oestrus periods (Roche, 1976).

The genetic impact and advantage of having a convenient practical method of synchronizing oestrus in farm animals would be through a greater use of AI so that a smaller number of sires would be required, thereby considerably increasing the possible selection differential. The best sires could be used on a larger percentage of the total population. Such a practice would, of course, have to be closely supervised by animal breeders so as not to cause any major increase in the level of inbreeding and loss of genetic diversity. Another practical advantage of oestrus synchronization would be the possibility of closer

managerial control of the female breeding herd during the breeding season and in producing large groups of marketable animals of about the same age and of similar genetic make-up.

In general synchronization of oestrus is not a technique that is likely to be adopted on any scale in the tropics but it is of interest to note that Abeyratne *et al*. (1983), in an experiment concerned with the synchronization of heat in cows and heifers owned by small farmers in two districts of Sri Lanka, claimed that although the resulting average pregnancy rates were low (39%) the exercise was well worth while as it exposed the farmers to the possibilities of assistance that veterinary extension work could offer and that it was possible to collect information on reproduction and other factors that could not have been obtained by other means.

Pregnancy Testing

Differentiation of pregnant from non-pregnant animals can be accomplished by measuring serum and/or milk progesterone levels as these fairly accurately reflect different stages in the reproduction cycle. This is the basis for practical pregnancy kits that are now generally available.

Multiple Ovulation or Superovulation

Superovulation has been demonstrated using domestic cattle, horses, sheep, goats, pigs and non-domestic species, though more work has been conducted with cattle than with the other species. The most suitable cows to be used for superovulation should be aged between 4 and 9 years, possess a normal reproductive tract and cycle effectively. Originally pregnant mare serum gonadotropin (PMSG) was used to superovulate cows but more recently FSH has been the hormone of choice.

Once the hormone has been administered the cows are inseminated two or three times 2448 hours after the onset of oestrus. The specific technology is detailed by Wagner (1987). Originally embryos were recovered by surgery but it is now normal to flush them out of the reproductive tract about 6 to 8 days after the onset of oestrus. After flushing the embryos are examined by microscope and evaluated. An economic and sufficient response would be the production of five to seven transferable embryos. According to Lindner & Wright (1983) embryos evaluated as excellent when inserted into recipient cows produced pregnancy rates as high as 80%, though the normal rate considered satisfactory is 5565%. Donor animals can be prevented from becoming pregnant by a luteolytic dose of prostaglandin F2 (Seidel, 1984).

Recipient Donor Oestrous Cycle Synchrony

The ideal recipient in cattle is a young, disease-free, well nourished heifer or cow that cycles regularly and is large enough to produce naturally a calf of the size of the implanted breed. Non-surgical transfer of the embryo can be made into the uterine horn under conditions of recipient-donor oestrous cycle and cell-stage synchrony. A 5565% pregnancy rate can be expected.

Embryo Storage

Since the late 1970s major advances have been made in the techniques of deep freezing and recovering embryos (Wagner, 1987). Survival rates of up to 80% can be expected.

'*In Vitro*' Production of Embryos

Oocytes recovered from slaughtered animals can be used to produce embryos. About 2.5 oocytes per ovary can be recovered. Some 20% of those matured and fertilized '*in vitro*' yield viable embryos. Alternatively oocytes matured '*in vitro*' and then fertilized '*in vivo*' with appropriate sperm capacitation, yield up to 7080% viable embryos in cattle, sheep, goats, and pigs. These can be developed to the one- or two-cell stage before transfer into the oviduct of the respective species (First, 1990).

Multiplication of Embryos

Multiplication of embryos can be accomplished in two ways, embryo dissection using

microsurgical procedures or cloning (nuclear transfer). In dissection the single cell is bisected to provide two separate cells, but there can only be a limited number of such splits. Alternatively single cells can be removed from two-, four- or eight-cell embryos to yield identical multiplets. Identical twins or multiplets produced in this manner could be a very valuable livestock research resource. The technique has been used in cattle, sheep and pigs. The cloning nucleus material is transferred from one cell of an individual to another. Wilmut *et al* (1997) have shown that viable offspring (a ewe named Dolly) can be derived from fetal and mammalian cells.

Possibilities for Sex Determination in Mammalian Livestock.

Manipulating the ratio between male and female offspring can offer managerial and economic benefits. Reasonably accurate methods have been practised for a long time by poultry farmers, but until recently no reliable method was available for dairy farmers. The subject has been reviewed by McEvoy (1992) and Jafar & Flint (1996). Theoretically, there are two possible and practical methods of manipulating the sex ratio in a species. These are:

(1) Separating the Y- and X-bearing spermatozoa in semen before its use for fertilization.

(2) Determining the sex of donor embryos and transferring those of the desired gender to recipient females.

Separating Y- and X-Bearing Spermatozoa

Encouraging results in separating Y- and X- chromosome bearing spermatozoa in semen have been obtained by using the technique of flow cytometry (McEvoy, 1992). In cattle the X-chromosome contains 3.8% more DNA than the Y-chromosome. Cran *et al* (1993), using flow cytometry, obtained Y-enhanced semen that produced 81% males overall and X-enriched that gave 94% females. The problems are that the sorting rate is very slow and there is some impairment of viability in the sorted spermatozoa. The sorting rate is so slow that it is impractical to use the technique to provide semen for conventional AI purposes but sufficient can be produced for *in vitro* fertilization. It is apparent that within a relatively short period some of the technical problems will be solved and that economic sexing of calves will become a practical proposition. The methodology can also be used for sex determination in some other mammalian species and in man.

Determination of Sex in Embryos

Several different procedures are being assessed; some more invasive than others. The most accurate and one of the least harmful appears to be the analysis of sex chromatin with a Y- chromosome specific DNA probe (McEvoy, 1992). A number of probes specific for sequence on the Y-chromosome of cattle now exist as does one for the Y-chromosome of pigs. Embryos would be 'flushed' from a donor female, sexed and placed in the uterus of the recipient female. Alternatively eggs could be flushed from the donor female, fertilized *in vitro*, screened and the required fertilized embryo placed in the recipient female.

Possible Application of New Reproductive Technology in the Tropics

It can be argued that the greater part of the new reproductive technology outlined above has little practical application in the tropics at the present time. Experimentally it could be useful but a major proportion of the work, the results of which may one day be applied in the tropics, are conducted in the temperate zone where facilities are already available.

This is not the case, however, for all the new technology. Synchronization of oestrus, pregnancy testing and sexing offspring are as likely to be useful in the tropics as in the temperate zone. The deep freezing of embryos is a technique that could become very important in the tropics, reducing the incidence of disease in breeding schemes and facilitating the transfer of tropical and temperate breeds from one continent to another. Multiple ovulation and embryo transfer technology could facilitate the establishment of multiple ovulation embryo transfer (MOET) breeding schemes that could be useful in the tropics.

The Basis of Inheritance

All tissues of the body consist of cells, differing in size and shape in accordance with their bodily function. They contain a substance known as *protoplasm* and among other characteristics they can metabolize nutrients, grow and multiply. A typical cell (Fig. 4.4) is surrounded by a membrane in which the *cytoplasm*, *nucleus* and *centrosome* can be distinguished. In the nucleus of the resting cell one or more *nucleoli* are present together with a large number of small particles known as *chromatin granules* that at specific stages of cell division appear as threadlike structure or *chromosomes*. These chromosomes occur in pairs. The total number of pairs and the size and shape of individual pairs vary from species to species (Table 4.4). There can also be differences between chromosome pairs within the same species, particularly those that determine the sex of the individual. Chromosomes possess the ability to multiply by division in step with the multiplication of cells while still retaining their individual characteristics. They are of paramount importance because they

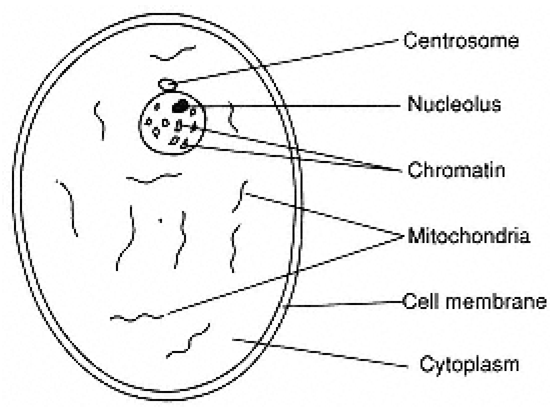


Fig. 4.4
Schematic representation of an animal cell.

Table 4.4 The diploid number of chromosomes in some domestic livestock species.

Species	Diploid ($2n$) number of chromosomes
Buffaloes	
River	50
Swamp	48
Camels	74
Cattle	60
Ducks	80
Fowls	78
Goats	60
Llamas	74
Pigs	40
Sheep	54
Turkeys	82

carry the coded messages or *genes* that transmit inherited characteristics from one generation to the next. The genetically active substance in the genes is *deoxyribonucleic acid* (DNA), which consists of two chains of nucleotides twisted together in a helical formation; the sequence of nucleotides in the formation determining the genetic information that is carried in the gene. As the number of possible total combinations of nucleotides is very large the quantity of genetic information that can be stored in this manner is extraordinary. When a cell divides, the helical formation of the DNA molecule splits lengthways, one chain of nucleotides going to one cell and the other chain to the other cell. In the two new cells the single chains of the split DNA molecule each act as templates, an exact copy of the single chain being synthesized in order to form a new DNA molecule exactly the same as the one from which the split chains originated. In this way each of the new cells acquires its full complement of chromosomes with their genes.

Cell Division

There are two sharply differentiated types of cell in the animal's body. *Somatic cells* that make up the body of the individual animal and are concerned with all body structures and most body functions, and *germ cells* that are concerned with the reproduction of a new generation of individual animals. When somatic cells multiply, the daughter cells are exact replicas of the mother cell, whereas when germ cells are produced the number of chromosomes is reduced to half the number for the species. Somatic cells are *diploid* and possess 2*n* chromosomes whilst germ cells are *haploid* and possess *n* chromosomes.

Somatic Cell Division or Mitosis

In mitotic division each daughter cell receives the same chromosome complement as was possessed by the mother cell by the mechanism described previously. Mitosis is a continuing process and it is the means by which the individual animal grows and replaces worn-out cells with new, healthy cells. A schematic illustration of mitosis is shown in Fig. 4.5.

Germ Cell Division, Reduction Division or Meiosis

The process of meiosis occurs in the same way in both the male and the female of the species. The male and female germ cells are produced in the manner described earlier in the section concerned with the reproductive cycle. It was stated in a previous paragraph that there are

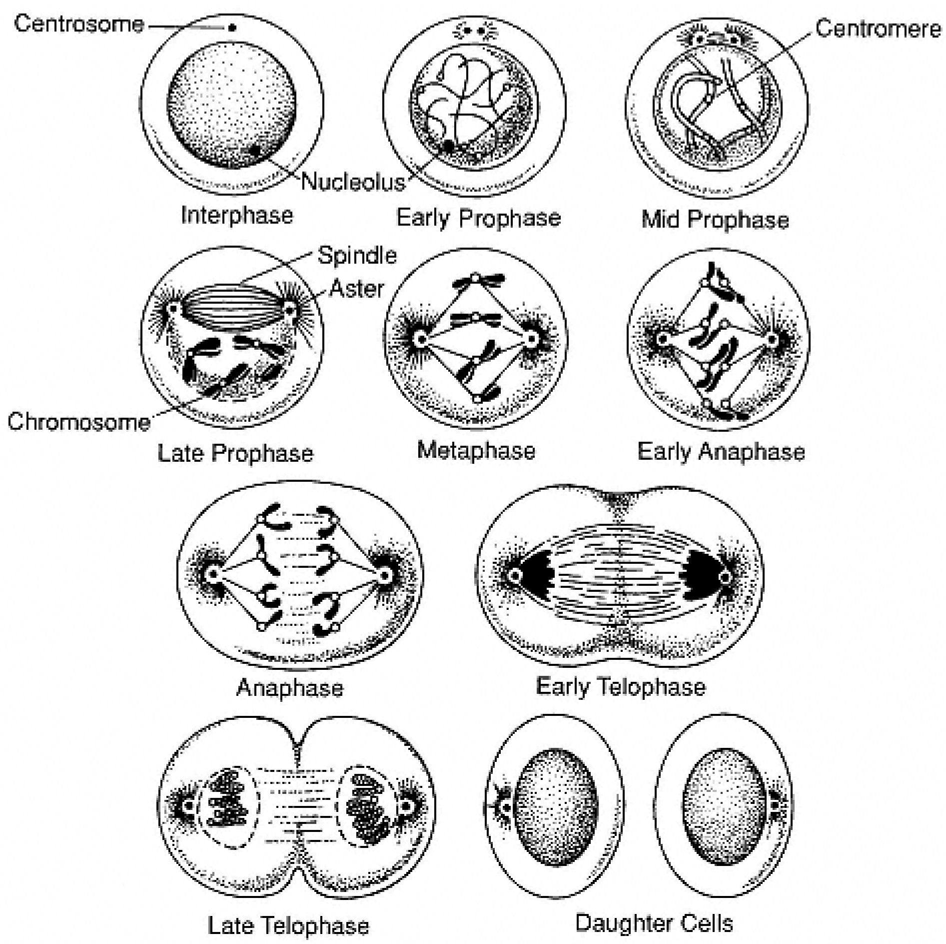


Fig. 4.5
Schematic illustration of mitosis.
(Source: Gardner, 1960.)

differences between chromosome pairs within the same species, in particular those that determine the sex of the individual. These chromosomes are known as the *sex chromosomes*. They also carry many genes for other characteristics and these are called *sex-linked characteristics*. The other chromosomes in the cell are known as *autosomes*.

Although the mechanics of meiosis are similar in the male and the female, each process will be described separately.

In the male the germ cells are found on the inner wall of the seminiferous tubules of the testicles. At sexual maturity these cells are stimulated by hormonal action to produce functional sperm. The process of meiosis begins with the *primary spermatocyte* growing and enlarging and finally dividing into two secondary *spermatocytes*. The division follows a process known as *synapsis* in which the pairs of like chromosomes known as *homologues*one member of each pair having been derived from each parentfuse together. During this process filaments of chromatin twist around each other, thus providing an opportunity for the exchange of genes from one homologue to the other. This is one of the mechanisms by which variation occurs, but there is of course no complete interchange of genes between one homologue and another.

After synapsis there is a separation of the fused pair of chromosomes, one homologue of each pair moving to one or other side of the cell (Fig. 4.6). After the polarization of the chromosomes is completed a new cell wall is formed with the production of two secondary spermatocytes, each containing one-half of the total number of chromosomes normal for the species. The haploid cells containing half the number of chromosomes are not of course identical with the parent cell or with the normal body somatic cells. The two secondary spermatocytes then divide by the process of ordinary mitosis to produce four *spermatids*. After a period of maturation the four spermatids develop into functional sperm with the characteristic tail, body and head. As the cell division proceeds, the mature sperm migrate from the wall of the tubule to the lumen or centre of the tubule through which they exit from the testicle in the manner described in the section concerned with the reproductive cycle.

The process of meiosis in the female is similar to that in the male with the exception that the primary germ cell or *oocyte* forms one *secondary oocyte* and one non-functional *polar body* (Fig. 4.6). Each contains one-half the normal number of chromosomes. The polar body differs from the secondary oocyte in that it has no yoke. The secondary oocyte and the polar body then further divide by the process of mitosis: the oocyte producing an ovum or egg and an additional polar body and the first polar body producing two polar bodies. The ovum thus produced is capable of being fertilized by sperm. The polar bodies appear to be non-functional and are absorbed.

The function of meiosis is to retain constancy in the chromosome number of the species and to ensure that both the male and female contribute genes to their offspring that are randomly representative of their characteristics. The haploid (n) egg contains half the number of chromosomes of the female parent when it fuses with the haploid (n) sperm that contains half the number of chromosomes of the male, forming a diploid ($2n$) zygote or fertilized egg that contains the number of chromosomes characteristic of the species.

The Inheritance of Characteristics

As the distribution of chromosomes and consequently of genes in meiosis is at random, this permits new combinations of paternal and maternal characteristics in the offspring. A knowledge of this process, and the ability to select individuals through various selection methods, provides an opportunity for the selection of animals possessing new combinations of genes that provide desirable characteristics required by man in his domestic livestock. It is also obvious that new combinations of genes may alternatively produce individuals with undesirable characteristics. These animals can be culled before they are allowed to breed and reproduce.

The process of meiosis does not necessarily

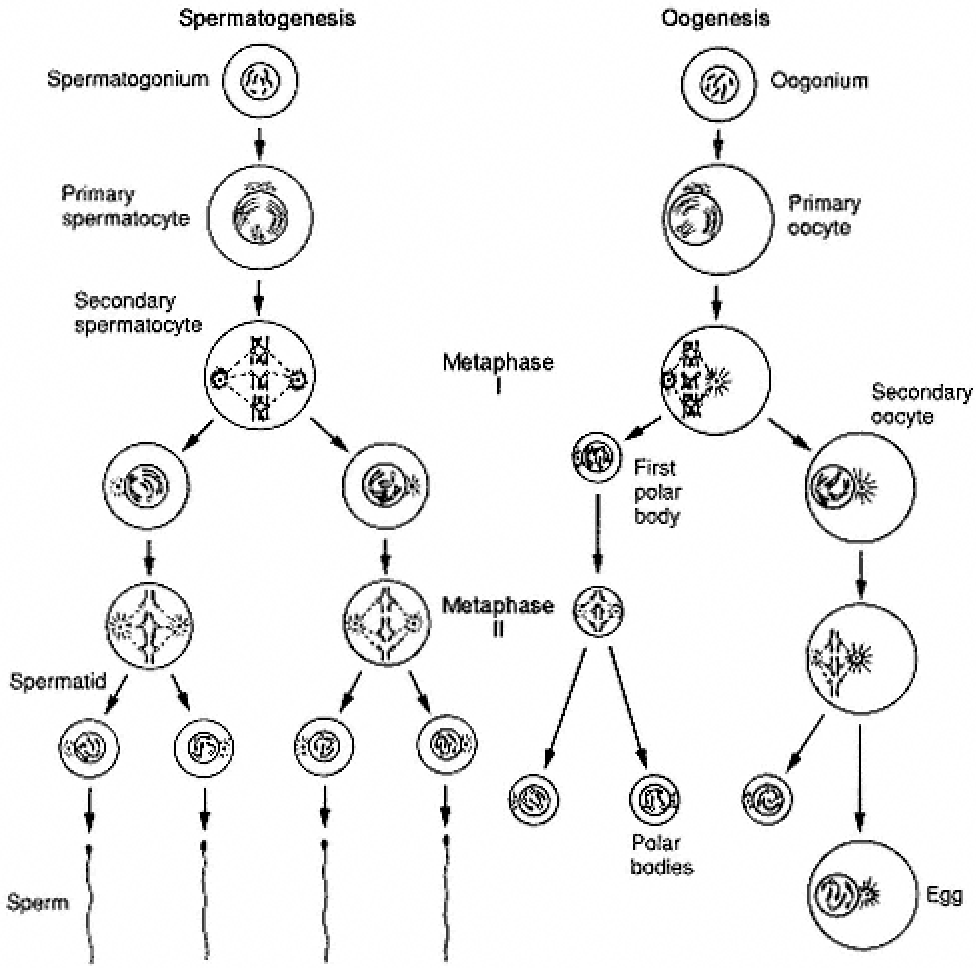


Fig. 4.6
Schematic illustration of meiosis.
(Source: Gardner, 1960.)

proceed smoothly on all occasions. There can be accidents during the process so that the normal number of chromosomes for the species is not always attained. These accidents may be due to non-disjunction, separation of parts of the chromosomes, abnormal pairing or non-pairing of homologues, etc. In addition, as explained in a previous paragraph, the arrangement of genes on the chromosomes can vary due to crossing over of genes during the process of synapsis. When variations due to these causes occur they will, of course, produce considerable and in some ways abnormal variations in the characteristics of the offspring. These phenomena are discussed in some detail in later sections.

Phenotypic differencesor the difference in the appearance of individuals both within and between specieshave been studied and theorized on by naturalists for a long time. In 1900, three botanists working independentlyDe Vries in the Netherlands, Correns in Germany and von Tschermak in Austriaproposed theories to explain the mechanism of the inheritance of individual characteristics. The work of these three botanists independently substantiated the work of an Augustinian monk, Gregor Mendel, who in 1866 had published papers that reported on data from 8 years of crossbreeding experiments using common garden peas. Mendel's work was known in both Europe and America, but the significance of his findings was not appreciated until De Vries, Correns and von Tschermak published their papers. In his papers Mendel proposed two basic laws on the inheritance of characteristics. These were:

(1) *The law of segregation*that the characteristics of an individual are determined by pairs of genes, but that their germ cells possess only one gene from each pair.

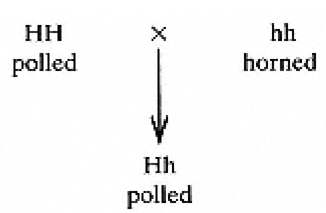
(2) *The law of independent assortment*that the genes combine at random with each other, both at the formation of germ cells and at fertilization.

Since Mendel's original publication there have been many modifications of these laws, but they are still fundamental for the whole science of genetics. The resulting overall interpretation of the laws of inheritance of characteristics is now known as the Mendelian theory of inheritance.

The practical significance of the first two laws of Mendelian theory are of extreme importance when man is selecting for specific traits in plants and animals. They will now be considered with reference to examples from domestic livestock.

As stated earlier the chromosomes occur in pairs and each homologue contains identical genes that occur in the same order in each homologue. These identical genes are known as *alleles*. Although the opposite genes are identical in that they affect the same phenotypic characteristic or development process of a character, they do not necessarily influence it in the same way. If both alleles have the same influence on a characteristic the individual possessing them is said to be *homozygous* for that characteristic, but if they differ in their influence the individual is said to be *heterozygous* for the characteristic. If the effect of one allele is stronger than that of the other to the extent that it masks the effect of the other, the masking allele is said to be *dominant*, while the allele that has been masked is said to be *recessive*. For example, in cattle the polled or absence-of-horns trait is dominant over the horned trait. Thus when homozygous horned cattle are mated with homozygous polled cattle the offspring possess one gene for the presence of horns and another for the absence of horns, i.e. they are heterozygous for the characteristic. Since the polled gene is dominant all the off-spring are polled (Fig. 4.7).

For graphic purposes, in order to express the actions of such genes, a capital letter is used to denote the dominant allele and a lower case letter to indicate the recessive allele. Thus, in the example given above, the homozygous horned individual would be designated as hh, the homozygous polled individual as HH and the heterozygous individuals resulting from the mating as Hh. The situation could then be expressed in the following manner:



The phenotypes of the HH and Hh individuals will be the same, i.e. polled, but their genotypesor their potential for transmitting characteristics to their offspringwill be different.

In some traits dominance is not complete. If this is the case and dominance is only partial then the offspring may exhibit phenotypic characteristics that are a blend of those of the two parents. A well-known example occurs in the Andalusian breed of poultry in which there are black and white varieties. If a black homozygous individual is mated to a white homozygous individual the offspring possess blue feathers. When an individual is homozygous for a recessive characteristic, such as is the case in the white variety of Andalusian poultry, the phenotype is the same as the genotype since the recessive trait has been neither masked nor modified.

An individual that is homozygous for one pair of genes has only one type of that gene to

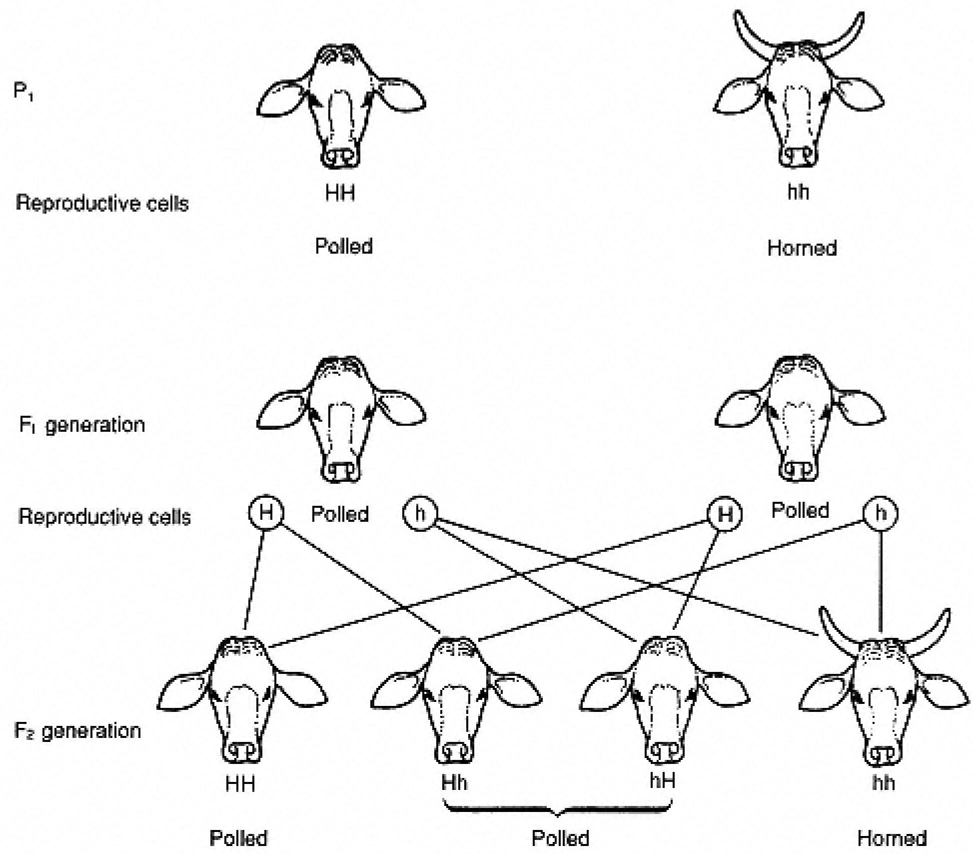
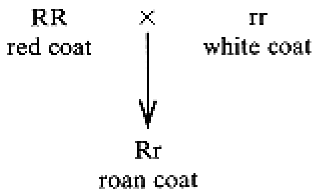


Fig. 4.7
Illustration of the inheritance of the polled trait in cattle.

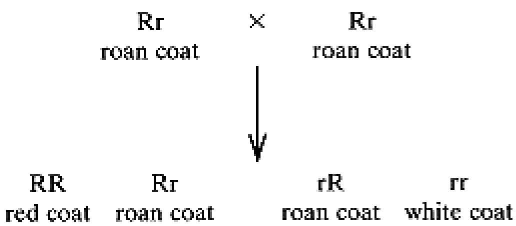
transmit and therefore breeds true. However, if an individual is heterozygous, it will have two types of the same gene to transmit. As only one of each pair of genes is transmitted to each germ cell at meiosis, any resulting fertilized egg could contain either of the two different types of the same gene. If the example of the transmission of horn or absence-of-horn characteristics in cattle is reconsidered it will be seen that when the polled heterozygotes (Hh) are intermated then, as both parents produce equal numbers of germ cells carrying either allele, the chances of any sperm cell from the male fusing with any egg of the same type or of a different type are equal and so four combinations of the genes are possible. These combinations are HH, Hh, hH and hh (Fig. 4.7).

Thus the result of a random fertilization is on average one homozygous dominant (HH) polled animal, two heterozygous (Hh) polled animals and one homozygous recessive (hh) horned animal. The phenotype grouping is therefore three polled to one horned animal, but since fertilization is at random it must not be expected in practice that among every four progeny of such matings the result will be three polled and one horned animal. This will occur only when a very large number of matings are evaluated. The chance of a recessive trait being exhibited under these circumstances is obviously one in four, and the chance of obtaining a true breeding individual from among those which phenotypically exhibit the dominant trait is one in three. The practical importance of this type of information is considerable when the animal breeder is selecting for specific characteristics.

An example of what happens when dominance is lacking in alleles can be demonstrated by reference to the inheritance of coat colour in Shorthorn cattle. If a red-coated Shorthorn is represented by RR and a white-coated Shorthorn by rr, then when red and white Shorthorns are mated the offspring are of a Rr type and their coat colour is roan rather than either red or white. This may be represented as follows:



If the roan offspring are intermated then segregation takes place as in the previous example. This may be represented as follows:



Thus, in this case, the phenotypic and genotypic ratios are the sameone homozygous (RR) red animal, one homozygous (rr) white animal and two heterozygous (Rr) roan animals with the heterozygotes being distinguished in appearance from either of the homozygotes. This was not the case in the example discussed previously of the inheritance of the polled trait. The genotypes HH and Hh appeared to be phenotypically the same and it would only be possible to distinguish them genotypically by performing a further breeding test, i.e. by mating them with animals of a known genotype and observing the progeny. For example, if the polled HH animals were mated with horned animals then all the progeny would be polled, whereas if the polled Hh animals were mated with horned animals half of the progeny would be polled and half would be horned.

The examples given above demonstrate the operation of the first Mendelian law on the segregation of inherited characteristics. The second Mendelian law, that of independent assortment, can be demonstrated in an example where the inheritance of two pairs of genes is considered at the same time. For example we can consider two dominant traits, polledness and snorter dwarfism in Hereford cattle. If a homozygous polled, non-dwarf individual with the genotype HHDD is mated to a homozygous horned, dwarf individual with the genotype hhdd then the resulting F1 progeny will be phenotypically polled and non-dwarf but genotypically HhDd. If the F1 progeny are then intermated the resulting offspring (F2) will exhibit four different phenotypes in the ratio of nine polled non-dwarf, to three polled dwarf, to three horned non-dwarf, to one horned dwarf individual. There will be, however, nine different genotypes (Fig. 4.8). The phenotypic ratio of 9:3:3:1 is mathematically the square of the ratio of 3:1, which is the phenotypic ratio when one characteristic is considered. If three pairs of characteristics that all exhibit dominance are considered then a phenotypic ratio of 27:9:9:9:3:3:3:1 will result. The number of possible combinations increases rapidly with an increase in the number of gene pairs. This can be seen from Table 4.5. Thus, in domestic animals where the number of heterozygous gene pairs is very large, it is not surprising that no two individuals, with the exception of identical twins, are genotypically or phenotypically completely alike.

Where dominance exists in one pair of genes but is lacking in the other the situation is different. For example, if we consider Shorthorn cattle where the polled trait is dominant and the coat colour trait lacks dominance, then if a homozygous polled red Shorthorn is mated with a homozygous horned white Shorthorn all the F1 progeny will be heterozygous polled and roan in colour (Fig. 4.9). When the F1 generation are intermated the following ratio of different phenotypic types of cattle would be obtained in the F2 generation: three polled and red, six polled and roan, three polled and white, one horned and red, two horned and roan and one horned and white (Fig. 4.9).

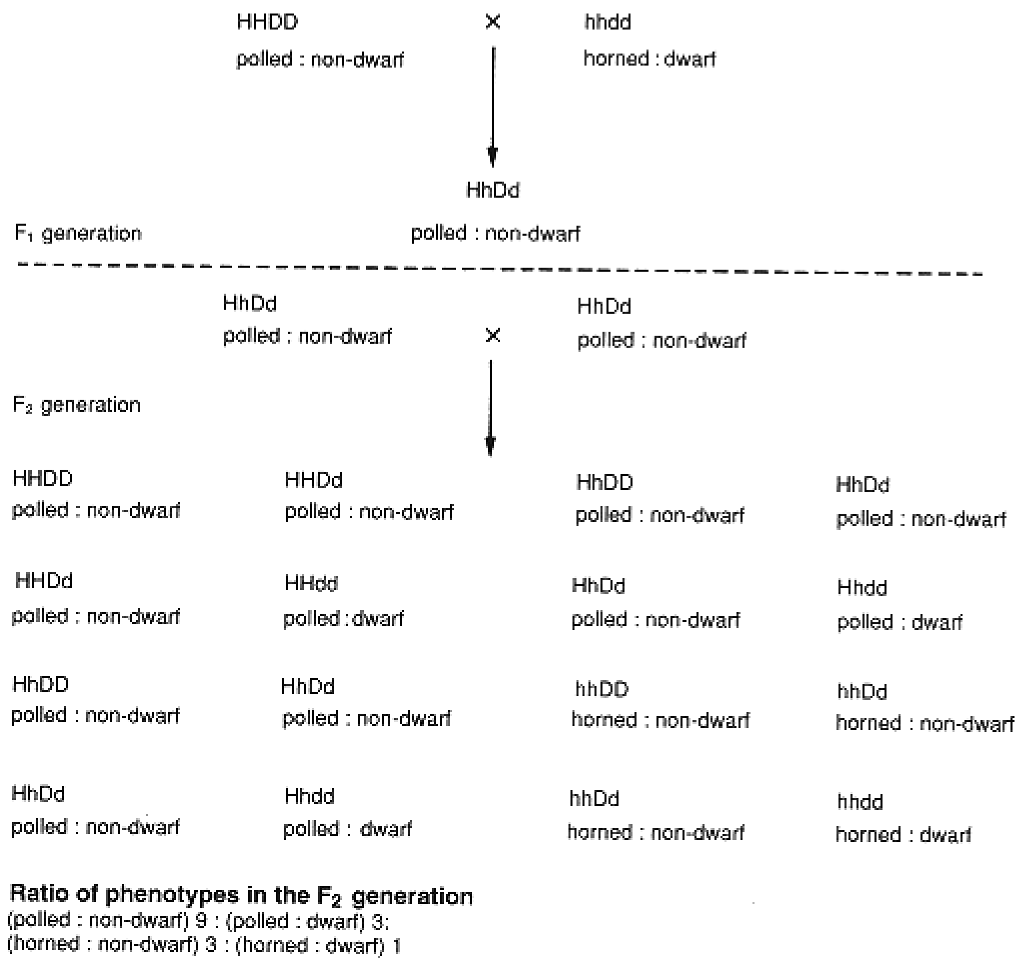


Fig. 4.8
Schematic representation of the inheritance of the polled and snorter dwarf traits in Hereford cattle.

Table 4.5 Combination possibilities in the F2 generation when F1 individuals are heterozygous for a specific number of gene pairs.
(*Source*: Johannsson & Rendel, 1968.)

Pairs of genes	No. of gametes	Combination possibilites	No. of genotypes	No. of homozygous combinations
1	2	4	3	2
2	4	16	9	4
3	8	64	27	8
4	16	256	81	16
10	1024	1 048 576	59 049	1024
n	2*n*	4*n*	3*n*	2*n*

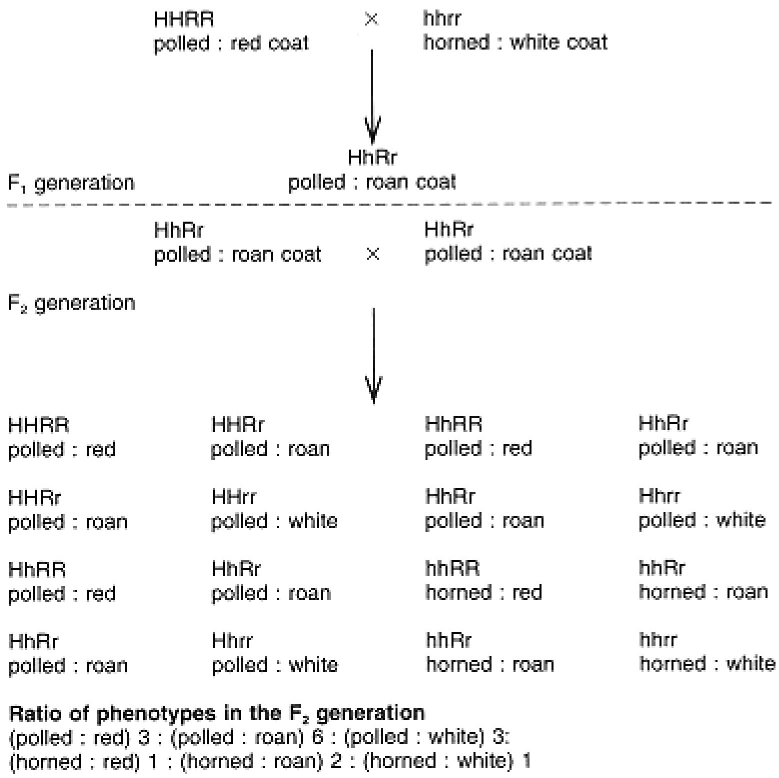


Fig. 4.9
Schematic representation of the inheritance of the polled trait and coat colour in Shorthorn cattle.

From the examples that have been discussed above it will be appreciated that if the mode of inheritance of traits is known then expected ratios of different types of offspring from specific matings can be calculated, as can the probability of obtaining a particular type of individual from a specific mating. There are, however, a number of important exceptions to these general rules.

Modifications of the basic Mendelian law may be necessary for a number of reasons. These include, among others, an additive effect of genes, the effect of duplicate recessive genes and the non-linear interaction effects between genes at different loci or *epistasis*. Also important are the effects of *linkage*, *crossing-over*, *multiple alleles* and disturbances in the chromosome mechanism. In general, no sharp distinction can be made between qualitative and quantitative characteristics. A characteristic may be determined by a major gene or *oligogene*, but one or more other minor genes or *polygenes* may cause some variation in the manifestation of the characteristic.

Where gene interaction is between alleles there may be *overdominance* if the heterozygotes are superior in one way or another to both the homozygotes. The occurrence of overdominance is assumed to play an important role in such qualitative characteristics as viability and fertility and will be further discussed in the section on crossbreeding. The effect may be due to one gene having a more advantageous effect than two genes of the same typei.e. a level of dosage effector to the alleles complementing each other in some way.

In epistasis, the effect of a single gene depends upon with which other genes it interacts. The effect on the normal additive situation can be either negative or positive.

An example of linkage is two characteristics that are somewhat related and not completely independent because they are controlled by genes that are located on the same chromosome rather than on different chromosomes. Under these circumstances independent assortment does not occur and the ratios of the phenotypes

may be different from those stated above, where it has been assumed that the genes are located on separate chromosomes.

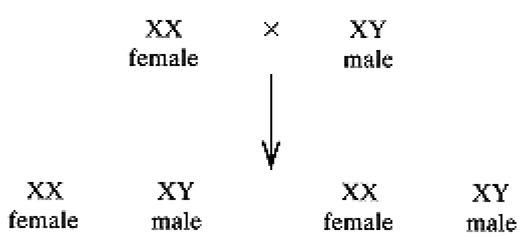
Crossing-over is said to occur whenalthough the genes are known to be located on different chromosomesin some way the genes stay together. It happens if chromosomes do not completely sort themselves independently but somehow a part of one chromosome joins up with a part of its homologue or vice versa.

It has been assumed in the examples of segregation and independent assortment given above that at any given location in the chromosomes there would be two alleles. More than two alleles can, however, be present and this also modifies the normal Mendelian ratios. One of the best-known examples is concerned with the inheritance of blood type in man. In this case there are four blood types derived from combinations of three allelic genes.

The livestock breeder is not of course usually concerned with the inheritance of one or two single traits. What is of major interest is the inheritance of quantitative characteristics such as body size, milk yield, the fat content of milk and the egg production of hens. It is therefore important to realize that although the fundamental laws of Mendelian inheritance still apply, characteristics of this type are strongly modified by environmental variation and that a very large number of genes are involved that may have different degrees of effect and interact in a complicated way with each other.

The Inheritance of Sex.

In the examples of inheritance that have been so far described it has been assumed that the genes were located in the autosomes and not on the sex chromosomes. The latter are different from the autosomes in that they are the primary determinants of sex in the offspring. In mammals the female possesses a pair of homologues known as the X-chromosomes, while the male possesses one X-chromosome and one that is very different called the Y-chromosome. The inheritance of sex can be shown schematically as follows:



Thus the sex ratio should theoretically be one to one. In farming practice the male:female ratio has been calculated to be 51.5, 52.3 and 49.2 for cattle, pigs and poultry, respectively (Johansson & Rendel, 1968). It is generally assumed that in mammals the male:female ratio at fertilization is considerably higher than 50%, but that the ratio is reduced during the gestation period because males have a higher fetal death rate. The reason why the sex ratio is higher at fertilization could be because for some reason sperm carrying the Y-chromosome are more viable. If there are differences in viability or mass between the sperms carrying the X- and the Y-chromosomes then it should be possible to separate them. This is a basis for some present proposed methods of sex determination.

In birds, the position is reversed the male is the homogametic (XX) sex and the female the heterogametic (XY) sex.

Other genes located on the sex chromosomes will obviously be linked or associated with sex and will be transmitted to the next generation in combination with sex. The fewer the chromosomes that the species possesses and the larger the sex chromosomes, the more traits are likely to be associated with sex and inherited in a sex-linked manner. To date, no sex-linked characteristics of economic importance have been recorded in mammalian livestock, but there are several in poultry. These include barred compared with dark heads, silver compared with gold down colour and curly compared with late feathering in chicks. Sex-linked inheritance of a colour factor has also been demonstrated in turkeys and geese. Man also demonstrates a number of well-known sex-linked characteristics, including haemophilia and red-green colour blindness. Haemophilia is also sex-linked in dogs.

It was thought at one time that the colour-marking genes could be used for the rapid determination of sex in chicks, but as poultry are bred strictly for their production characteristics breeders could not afford to restrict their breeding programmes to the breeds exhibiting sex-linked colour traits. In any case sexing by examination of the external genitalia of day-old chicks is now commonplace so that the economic need for a colour determinant of sex in the chick has declined.

Nevertheless, efforts to utilize colour-marking genes continue. A strain of fast growing broiler chicks that can be sexed at hatching has been introduced by a poultry breeding company. The females possess a golden tinge to their down, whilst the males are silver white.

A schematic diagram of the sex-linked inheritance of barring is shown in Fig. 4.10. When a black cock is mated with a barred female, in the F1 generation all the males are barred and the females are black. After hatching the difference between the sexes can be seen immediately as the male chicks have a light patch on the back of their head and are relatively light coloured on the other parts of the body while the female chicks possess down of an even colour.

The White Leghorn breed possesses a sex-linked gene for early feathering, an economically desirable characteristic as it is linked with early maturity and the chicks are less liable to chill, whereas some of the heavier breeds have a corresponding dominant allele for late feathering. If White Leghorn cocks are bred to the heavier breed hens the female chicks exhibit the early feathering trait.

Autosexing breeds (those in which sex is correlated with some external, easily recognizable, bodily feature), such as the Legbar and the Cambar, have been produced, but they have not been particularly popular as they have not been so productive as some other non-autosexing breeds.

Mutation

There are many examples of the sudden appearance of variants or 'sports' in livestock. The process is known as *mutation*. It may be defined as

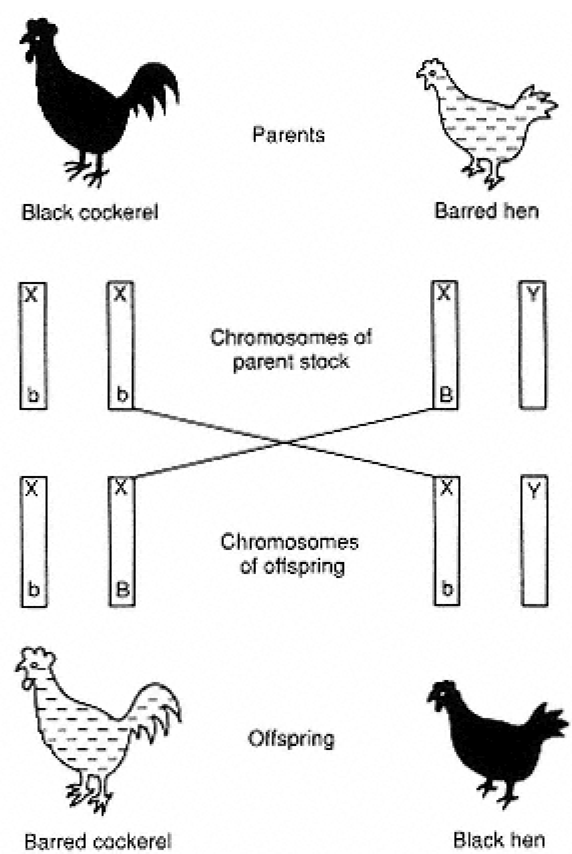


Fig. 4.10
Illustration of the sex-linked inheritance of the barring trait in poultry.
(Source: Hammond *et al*., 1971.)

every change in the heritable sense which is not due to segregation or to a recombination of previously existing genes. This spontaneous change may be due to a variety of reasons, and there is presumably a change in the chemical composition of the gene.

Mutation can take place in both somatic and germ cells; it occurs naturally at all times, but its frequency can be increased by the effect of radiation and certain chemicals. Natural mutations apparently occur at rates ranging from one in 100 000 generations to one in 10 million generations. The majority of visible mutations appear to be generally undesirable as far as the livestock breeder is concerned, but more of them may be advantageous for the breeders of fancy pet animals. It is believed that the majority of the fancy breeds of dogs, cats, rabbits and various species of birds owe their origin to a mutation. If the mutant is a dominant gene the trait that it controls should be exhibited immediately, but if it is a recessive gene the trait may be hidden for generations.

It must be presumed that animals gradually acclimatize themselves generation by generation to a new environment partly on account of mutations that are favourable to them in their new environment.

If a single gene has a multiple effecta phenomenon known as *pleiotropy*even mutations that could be considered to be desirable may have other effects that are very undesirable. For example, double muscling in beef cattle might be considered economically desirable, but when the trait is inherited in the homozygous form it is also the cause of unthriftiness and infertility. Another interesting example is the link between polledness and intersexuality of female goats. The polled condition can appear due to a mutation in horned goats, and as it is a dominant character it would be expected that it should be possible to breed hornless goats. This is not normally the case as homozygous polled females are intersexual and therefore sterile, and homozygotes are required in order to be able to breed for total hornlessness.

Many of the abnormalities common in livestock are due to mutations. Those that cause the death of the fetus are known as *lethal factors*. Others such as cleft palate, hernia, inverted nipples and *atresia ani* in pigs and cryptorchidism in cattle, sheep, goats and pigs cause difficulties after birth. The many types of coat colour in domestic livestock have all been derived by mutation from a more limited number of coat colours in wild animals. Abnormalities are often associated with white coloursuch as the underdevelopment of the vagina and uterus in white Shorthorn heifers. Details of known lethal factors in livestock in the temperate zone have been published by Lerner (1944). The majority of abnormalities noted in temperate-type stock are also known to occur in tropical-type livestock.

Domestic livestock can and should be purged of unwanted mutations that cause abnormalities, particularly if male animals are going to be used to mate with a large number of females either naturally or by using artificial insemination (AI). If the male is homozygous for the abnormality, then he will normally exhibit it so that his elimination from a breeding programme is simple. If he is heterozygous he may not exhibit the abnormality. He should be mated with two or three females of the same breed that exhibit the abnormality. If he is heterozygous for the trait half the resulting offspring will exhibit the trait; if he does not possess the trait then none of the offspring will exhibit it. Heterozygous males can thus be identified and culled.

Changes in the Number of Chromosomes

When the chromosome number of a type or species is a multiple of the haploid chromosome number (n) and larger than the diploid number ($2n$) it is usual to refer to it as a *polyploid*. Changes in the chromosome number have been mainly studied in plants and lower animals, and although *polyploidy* may have played a role in the evolution of animal species, little is at present known of its incidence in livestock. In this context it is interesting to note that in man possession of an additional X-chromosome, i.e. the male possessing XXY-chromosomes instead of the normal XY, may be one cause of intersexuality.

Genetic-Environmental Interactions

The suggestion by Hammond (1947), that livestock should be reared and bred in the most favourable environment if maximum improvements are to be made through selection, has been generally accepted in the temperate zone. However, this theory may not be completely sound if the differences between the environments in which the livestock are bred and used are very great, as they are between temperate and tropical environments. Geneticenvironmental interactions may in fact be very important for the livestock breeder in the tropics. They may be defined as the differential response of a specific genotype in different environments.

One obvious effect of the environment on the genotype is on the mature size of domestic livestock. Under natural grazing conditions in high-rainfall areas, where minerals have been leached from the soil, domestic livestock are generally smaller than genetically similar animals managed in the drier areas where there is little leaching. An example occurs in East Africa where semi-arid-area cattle, such as the Boran and the Karamajong, are on average much larger than the East African Shorthorn Zebu that are found in the more humid areas, although it is highly probable that all these zebu breeds had a common ancestry. In India virtually all breeds of zebu hill cattle are on average smaller in size than the zebu cattle found in the adjacent plains although they almost certainly possess a common ancestry (see Chapter 7).

Apart from such general observations there is experimental evidence scattered throughout the literature. For example, Barlow & O'Neill (1980) showed that there were a number of significant interactions between the breed of the sire and environmental variables for measures of preweaning growth of crossbred calves in the Australian subtropics. Later, Barlow (1981) suggested that the heterosis effect may be dependent on the level of the environment, and came to the general conclusion that the more stressful the environment the greater the expected effect of heterosis.

The reasons for geneticenvironmental interactions are probably varied. One reason that has been suggested is that the genes affecting a particular trait in an animal may not be the same in two very different environments. It is also possible that the effect of a specific mutation might be very different in different environments. For example, a mutation for additional or longer body hair could be very advantageous to an animal in a cold, temperate climate and very disadvantageous in a hot, humid tropical climate.

What is certain is that the planning of breeding programmes in the tropics depends as much on the magnitude of geneticenvironmental interactions as it does on other genetic parameters. Readers who are particularly interested in interactions with regard to specific livestock should consult Pani & Lasley (1972).

Maternal Influence

The mother has a very considerable influence on the development of her young during the gestation and suckling periods. Usually the birth weight decreases with an increase in the number of young born. In cattle and sheep the birth weights of individual twins are 2530% lower than the birth weight of singles.

When reciprocal crosses are made between large and small breeds there is no experimental evidence to suggest that under most circumstances the maternal influence during the gestation period has any influence on body size at maturity of the offspring. Differences have, however, been noted where the disparities in size are extreme, i.e. between the Shire horse and the Shetland pony and between the Flemish Giant and the small Polish rabbit. Experimental work does not support the idea that the mother has, in the long term, any special influence on the offspring or that the offspring inherit more traits from their dam than from their sire. Differences that occur in the mature offspring of reciprocal crosses of extreme animal types must be considered to be due to carry-over effects of differences in the fetal and suckling environments.

To what extent the age of the mother influences the frequency of congenital defects in domestic livestock is unknown. It has been shown that there are many instances of congenital malformation in domestic livestock where a change in the environment can have the same effect as a change in the genetic constitution of the animal. This phenomenon is known as *phenocopy*. Phenocopies of a number of genetically determined deformities in the offspring can be obtained by injecting the mother with specific chemical substances during the first part of her gestation period. Deficiencies of vitamins can also induce deformities in the fetus. In practice, it is suggested that deformities in young livestock should be scrutinized very carefully before they are necessarily attributed to the effect of heredity.

Animal Breeding Practices

Current animal breeding methods will be briefly discussed and the ways in which these practices can best be used in tropical environments will be considered.

Selection

In order to improve the average level of a livestock population for any trait by genetic means the population must be subjected to selection for the specific trait or combination of traits required. Some traits are strongly inherited while others are weakly inherited as their development in the animal is more dependent upon environmental conditions. The intensity of inheritance of a specific trait can be measured. This is known as the *heritability* of the trait, is usually symbolized as $h2$, and it may be defined as those phenotypic differences in a trait that can be attributed to inheritance. It has been found that those parts of the animal that develop early in life tend to possess higher heritabilities than those parts that develop later, and that heritability estimates are least variable if they are determined under standardized environmental conditions. Approximate estimates of the heritabilities of a number of selected productive traits in domestic livestock are shown in Table 4.6. It will be seen from this table that carcase traits are generally highly inherited, that liveweight gain and efficiency of feed conversion are moderately highly inherited, that milk and egg production are relatively poorly inherited and that traits such as fertility and viability are very poorly inherited.

Heritability provides an index of the probable efficiency of selection. Where heritabilities are high the most effective programme for genetic improvement of the trait would be mass selection of those individuals exhibiting the desirable trait with little attention being given to ancestry, sibs and other collateral relatives, and to progeny tests. Where heritabilities are low selection should include some form of progeny test and be based on ancestry and the performance of close relatives.

Selection acts by allowing selected individuals to contribute more traits to the next generation than other individuals in the same population. In fact the unselected individuals will have no influence on the next generation as they will not be allowed to breed. The rate at which selection can improve a population depends upon its overall accuracy, its level of intensity and the interval between generations.

Accuracy in selection depends upon how well the phenotype reflects the genotype and this can be improved by keeping as many records as is economically practicable. For example, the heritability of milk yield estimated from a single lactation record of a milking cow may be 0.25, whereas when two, three and four lactations are included in the estimate the heritabilities may be 0.33, 0.37 and 0.40, respectively. Stress must, however, be placed on the economic practicability of record keeping. Multiple and complicated records do not necessarily provide additional information as to how accurately the phenotype reflects the genotype. The intensity of selection depends to a very large extent on suitable replacement animals being available. Thus improvements in overall fertility and mortality improve the possibilities for intensifying selection. The interval between generations depends upon the interval between birth and sexual maturity and the fertility rate. Any improvements in the age at first parturition and in overall fertility will help to decrease the interval between generations and thus increase selection pressure.

Four major methods of selection are used in practice: individual selection, pedigree selection, selection on the basis of collateral relatives and progeny testing.

Individual Selection and Performance Testing

This is a most valuable method where a trait is highly inherited and where it can be observed in

Table 4.6 The approximate heritability of selected traits in some domestic livestock.

Type of livestock	Trait	Approximate heritability (% *h*2
Beef cattle	Score for tenderness of meat	5565
	Dressing percentage of	5565
	carcase	4555
	Bone percentage in carcase	4555
	Heart girth measurement	4050
	Daily liveweight gain	3545
	Efficiency of feed	3545
	conversion	2025
	Birth weight	
	Weaning weight	
Dairy cattle	Butterfat percentage in milk	5060
	Protein percentage in milk	5060
	Butterfat production	2030
	Milk production	2030
	Reproductive performance	010
Sheep	Daily liveweight gain	5060
	Staple length of wool	4050
	No. crimps per unit length	4050
	in wool	2535
	Birth weight	2535
	Weaning weight	
Pigs	Score for leanness of meat	6575
	Body length	4555
	Back-fat thickness	4555
	Daily liveweight gain	4050
	Efficiency of feed	3540
	conversion	
Poultry	Thickness of eggshell	3545
	Egg production	2030
	Age at first lay	1525
	Hatchability of eggs	1015
	Viability of eggs	1015
	Fertility	05

The majority of the estimates have been made in temperate-zone countries.

both sexes. In order to compare animals from different herds and therefore from slightly different environments the animals to be tested must be brought together under the same conditions of feeding and management. An arrangement of this type is called a *performance test*. It can, of course, only be used for selecting for traits that can be measured in the live animal, such as growth rate and efficiency of feed conversion. However, the recent development of ultrasonic carcase measurements has meant that some carcase measurements can also be made. The major use of the performance test is for the selection of suitable breeding males.

Pedigree Selection

This is a method of selection based on the performance of ancestors. It was, until recent times, the major method by which selection was practised and it spawned a network of pedigree herd societies. The method can be of value only if the

pedigree information is complete. Today, pedigree information is most useful when no data are available for the individual animal, either because it is too young or because the expression of a trait is sex-linked. The principal use of a pedigree in animal-breeding practice is to avoid too close an inbreeding ratio.

Selection on the Basis of Collateral Relatives.

This is most useful when family size is large, when traits are highly inherited, when there is a close genetic relationship between members of the family and when the mean generation interval is short. It is, therefore, obviously of more use in selecting for productive traits in poultry than in cattle.

Progeny Testing

The assessment of the breeding value of an animal on the basis of the performance of its offspring is known as a *progeny test*. As in most livestock species males produce many more offspring during their lives than females, progeny tests are usually applied to males. It is a particularly valuable method to employ where a trait such as milk production is not measurable in mature animals of both sexes, where the heritability of a trait is low, where the breeding unit is large and where the increase in the generation interval, implicit in the methodology, is not too pronounced. Selection accuracy is increased at the expense of selection intensity and an increase in the interval between generations. Progeny testing is widely used in order to improve milk production in the temperate zone, but so far this method of selection has not been used to any major extent in the tropics.

Aids to Selection

Artificial Insemination (AI)

This method of breeding can now be used for every species of domestic livestock and for some wild species. According to White *et al*. (1981) the use of AI has increased milk production in North America by about 1% per annum. It has probably had a major impact on cattle breeding and bull selection in temperate countries. Nevertheless, its usefulness is not unlimited and it can be practised successfully only under quite specific practical conditions. Its misuse can lead to a rapid loss of genetic diversity.

AI enables the selection differentials of bulls to be greatly increased and more accurate estimates to be made of their breeding value for traits expressed only by cows. Thus the benefits to be derived from AI are that it allows maximum exploitation of the best sires, the fullest use of selected sires and a reduction in the total number of sires that have to be maintained. When AI is properly organized in a region there can, therefore, be a significant reduction in overall cattle breeding costs. AI can minimize the spread of venereal and other diseases. As AI demands that the farmer should closely observe his female stock, it also probably improves general standards of management. Certainly it is a method by which livestock owners and livestock extension staff are brought into closer contact with each other and it probably stimulates a general increasing interest in livestock improvement.

It is a method that is of particular utility to livestock farmers who wish to use different breeds of sires simultaneously, and is likely to be economic in areas where there are a large number of smallholders, the majority owning one male and a limited number of female stock. It can also be of the greatest use where it is desired to import exotic livestock for crossbreeding and/or upgrading purposes, and where it is doubtful whether exotic sires will thrive. As AI involves the close handling of animals it cannot be undertaken on an economic scale where the livestock are too wild or too dispersed on the holding. Nor is it normally economic to service widely separated farms, particularly where roads and telephone communications are poor or non-existent.

There are also some special technical problems for AI in the tropics. In most countries the low level of farm recording has been a major handicap in the testing of AI bulls. Obviously little is to be gained and considerable harm may be caused if the sires used in an AI programme are unproven and not known to be superior to most local sires. If they are not proven they could in fact be inferior to some local bulls that would otherwise be used for natural service. Another problem is that many livestock-owning peoples in the tropics rear all their male animals to maturity for work or meat purposes, so that the use of AI does not reduce their costs in bull maintenance. Perhaps the most serious technical difficulty is that in the females of many tropical breedsin particular in the females of the zebu or humped cattle breedsheat periods are short in duration and often difficult to identify as they frequently occur at night. Under these circumstances many heat periods may be missed and this seriously reduces the efficiency of the AI operation. Short and silent heats are also very frequent in the females of exotic dairy breeds managed in the tropics, and in consequence AI in many exotic dairy herds has tended to become an uneconomic operation.

A further technical problem is that fresh semen must be used very quicklyin less than 24 hoursand at ambient temperatures above 40°C sperm viability is lost even more quickly Semen chilled to 5°C has a shelf life of 35 days, but its viability declines with each day of storage. The only really practical AI method to use in the major part of the rural tropics is one based on the use of deep-frozen semen. This semen is stored at -70°C and has a shelf life of at least 5 years. However, the equipment is expensive and a guaranteed supply of liquid nitrogenthe coolant generally utilizedmust be available.

It is apparent that the organization of an AI service is not necessarily the ultimate answer to livestock-breeding problems in any tropical country. In fact it may be an inefficient method of using scarce resources.

Technological improvements in AI, such as the introduction of deep-frozen semen, may have improved the possibilities of importing the semen of exotic breeds into the tropics and may have solved some of the problems posed by scattered holdings and poor communications, but these new techniques require even more equipment and highly skilled manpower than the old and due consideration should be given to all the relevant factors before they are introduced.

Embryo Transfer

The techniques involved and the results obtained to date have been discussed in a previous section. Superovulation and embryo transfer are an additional tool or aid for the animal breeder and can be used to advantage in the following ways:

- Genetically superior productive females can be used to supply additional ova that can be fertilized and the embryos transferred to less productive females in the herd, thus improving overall genetic gain in production within the herd. This technique can be used to establish multiple ovulation embryo transfer (MOET) breeding schemes.

- Genetically superior females that on account of injury, disease or old age, are unlikely to give birth can provide valuable embryos for transfer purposes. Even when slaughtered, oocytes may be recovered from such females to produce embryos that may be transferred to nurse cows.

- A high proportion of cows in beef herds could carry and raise unidentical twins, one twin being the result of an embryo transfer.

- To improve the possibility of importing genetically superior types or species into new environments, because:

  embryos are less likely to transmit disease than semen or live animals; and

  the young born after the transfer of imported embryos to indigenous recipient females could obtain appropriate passive immunity factors for the environment from their foster dam's colostrum and possibly survive better than directly imported animals.

The use of at least two of the techniques listed above could be beneficial in the tropicsMOET and the use of embryos to improve the possibility of introducing new breeds or species into new environments.

The basis of the MOET breeding schemes mentioned above is that full sisters and paternal half-sisters of young dairy bulls on test are produced contemporaneously by multiple ovulation, *in vitro* fertilization and with the embryos being transferred to recipient cows in a nuclear herd. Resulting daughters are then milked under controlled conditions and the yields used to evaluate the genetic merit of the bulls. The major advantage of MOET schemes is that in the temperate zone they reduce the time needed for evaluation of bulls from about 6 to 3 years. The disadvantages are that there could be a high level of inbreeding and that success depends on factors such as the size of the nuclear herd, the number of embryos produced and their survival (Luo *et al*., 1995).

A central facility is needed and the herd should be managed as an open nucleus breeding system (ONBS) (Fig. 4.11) with cows from the field being brought into the central station to act as donors of ova and recipients of embryos. This is a system that in the opinion of the authors, could be operated successfully in tropical regions where extensive field AI and recording is often difficult and sometimes impossible and where there are a limited number of well-educated farmers.

An example of the use of embryos to introduce a new breed into a new environment has

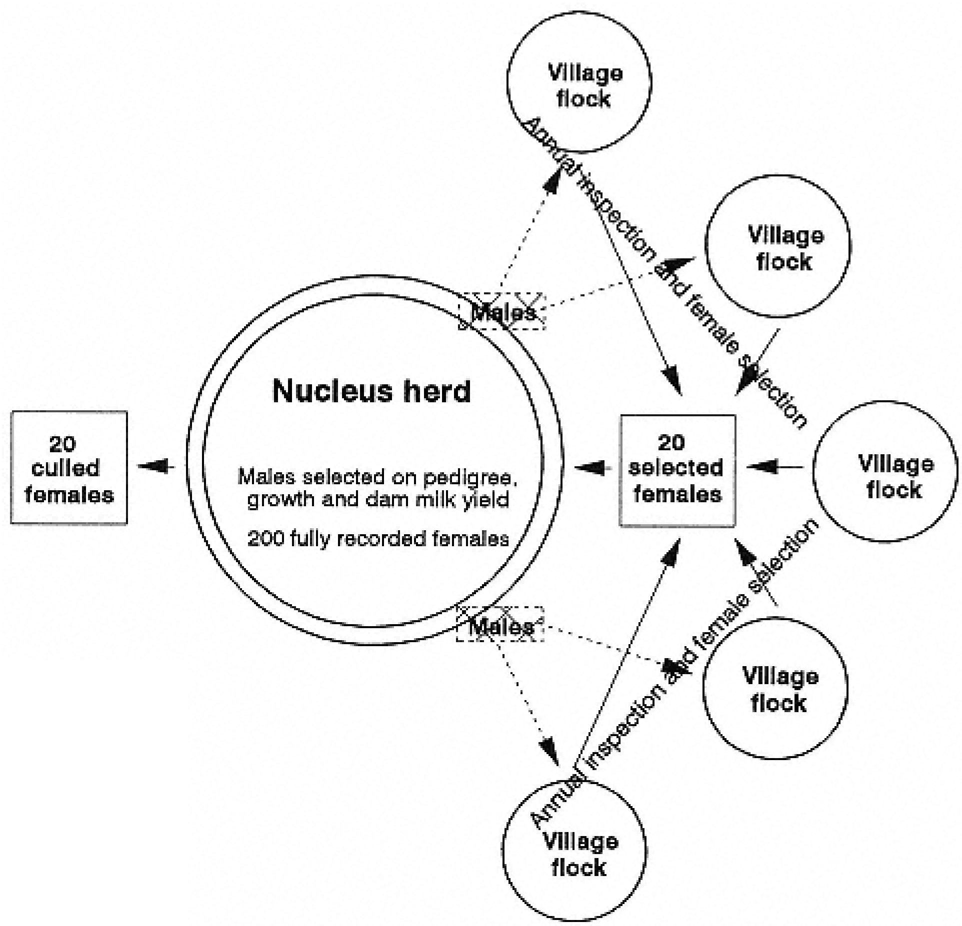


Fig. 4.11
Diagrammatic representation of an open nucleus breeding system (ONBS).

occurred in Africa. N'Dama cattle have been successfully imported into East Africa by transferring stored N'Dama embryos from West Africa into recipient East African zebu cows in Kenya. This particular transfer was for research purposes but the scope for intercountry, intercontinental and interclimate transfers of livestock is very great and no doubt this technique, which could be of particular interest in the tropics, will be rapidly developed and improved.

Contemporary Comparison Test

A sample of the average milk yield of unselected heifers in a number of herds under test is compared with that of contemporaries sired by other bulls. The comparisons are between heifers of approximately the same age and sexual maturity and are made in the same time period. This is therefore a method of testing dairy bulls under farm conditions. It is not likely to be a method of major importance in most tropical countries, however, as it is only applicable in farming systems in which there is a high level of recording.

Testing Stations

Special centres for progeny testing have been established for the selection of pigs, poultry, dairy and beef cattle in a number of countries. At these centres housing, feeding and general management are standardized. For example, in the testing of dairy bulls in Denmark 1820 daughters of each of the bulls to be tested are chosen at random from different herds without reference to the production of their dams. The heifers must be of approximately the same age and sexual maturity. They are brought together in the testing station at least 3 months before parturition and retained until they have completed one lactation. Comparisons between bulls are then made on the basis of performance of the progeny groups at the test stations.

Progeny-testing stations could be used in many tropical countries, with the added advantage that good husbandry methods might be demonstrated to the livestock owners whose animals are under test. The major problem would be economic, i.e. the cost of such stations in relation to the overall benefit that might be expected.

Selection Indexes

Often the livestock breeder is concerned with selecting for more than one trait in an animal at any one time. There are three major methods by which he may proceed. First, selection of each trait separately and simultaneously. Secondly, selection for one trait at a time in succession; known as tandem selection. Thirdly, selection for all traits simultaneously in accordance with some form of selection index. This latter method can be satisfactory, unless there is a high negative correlation between any two of the traits included in the index. An example would be an attempt to select for high milk production and heat tolerance in dairy cattle in the tropics. These two traits are negatively correlated as high milk production increases heat production that reduces the heat tolerance of the cow. In order to construct a suitable selection index the breeder requires information on the heritabilities of the relevant traits, genetic and phenotypic correlations between the traits and their economic value.

Recent advances in genetic theory, increases in the power of computers and the development of special computer programs have resulted in the development of new, sophisticated methods of predicting breeding values (Hill & Meyer, 1988; Pollack, 1988). These are mainly based on a methodology known as BLUP (best linear unbiased prediction). Using such methods unbiased comparisons can be made between the breeding values of non-contemporary animals.

Selection on the Basis of Correlated Characteristics

Obviously if a trait could be found that is easily observed and/or measured and that is correlated with productivity, then that trait could be used for selection purposes. One such trait has been noted that can be used for selection purposes in the tropics, particularly when exotic livestock are imported: the trait of woolly-coatedness. It was first reported from South Africa that woollycoated beef cattle were poorer performers than sleek-coated animals of the same breed in a hot climate and the original observation has since been confirmed elsewhere. Selection for sleek coat can lead to a rapid change in coat type and improvements in growth rate and fertility in beef cattle in the tropics.

Measurement of Genetic Change.

The degree of genetic change in a livestock population can be measured, but the methods employed require the use of very accurate, complete and numerous herd and flock records. These are not generally available in tropical countries.

The Use of Selection Techniques in the Tropics

Although selection has led to immense improvements in the productivity of livestock in the temperate zone, in the tropics it may not be so effective a breeding tool in the initial stages of development as some other breeding practices. For example, although it may be relatively easy to increase the number of functional teats in female breeding pigs by culling those that do not possess at least 14, it may be very difficult to increase rapidly the milk production of indigenous tropical cattle. Mahadevan (1966) has estimated that the genetic improvements in milk production that have been made in tropical breeds of milking cattle by selection have never averaged more than 1% per annum. If it is accepted that present average milk yields in most breeds are of the order of 7001400 litres per lactation, then it will be realized that selection to achieve even medium milk yields could take a very long time. The reasons for this situation are that any improvement programme begins from a low base, superior genotypes for milk production are probably extremely rare in tropical breeds (Mahadevan, 1966) and geneticenvironmental interactions can be large (Payne & Hancock, 1957; Pani & Lasley, 1972).

Selection techniques cannot, however, be ignored in the breeding of more productive tropical livestock. Even if it is accepted that crossbreeding is, at the present time, the breeding method most likely to improve the productivity of tropical livestock, selection programmes are still required. Selection of suitable males within the indigenous breeds is needed, whether rotational crossbreeding is practised or grading up to F1 males. Similarly, if an indigenous population is replaced by top-crossing with an exotic breed or a synthetic population formed from planned proportions of indigenous and exotic genes, selection will ultimately be required.

Inbreeding

The mating of close relatives is known as inbreeding. To be strictly correct the term should be used to describe the mating of individuals who are more closely related in descent than randomly chosen mates. The chances are that the closer the relationship the more the individuals will possess characteristics in common. If each has the same parent each will carry, on average, half the genes of each parent. If the relationship is through grandparents the chance of similarity in genotypes is halved, this process proceeding through each receding generation. In farm animals the closest relationship that can be procured will be brother × sister, sire × daughter or dam × son. As would be expected, inbreeding increases homozygosity as the number of genes in common is increased in every generation.

The quantitative measure of the degree of inbreeding is known as the *coefficient of inbreeding*, which measures the amount by which heterozygosity is reduced. As examples, the coefficients of inbreeding of sire × daughter, brother × sister and first cousin matings are 25.0, 25.0 and 6.25%, respectively.

Effects of Inbreeding

Both dominant and recessive traits are involved in inbreeding so that success or failure of this system tends to depend upon how many undesirable recessives are carried by the parent stock. This is because the system concentrates in the offspring the bad as well as the good traits of the parental stock. It is for this reason that the system is so often described as dangerous or undesirable. Not only does the concentration of undesirable recessive genes produce an increase in the number of specific abnormalities in the offspring, such as the bulldog condition or recessive achondroplasia in calves but, perhaps more importantly, it causes a decrease in size and vigour, a decline in fertility and an increase in the mortality of the offspring, thus leading to a decline in total productivity. Of course it can be argued that if the parent stock is generally free of undesirable recessives then inbreeding will concentrate desirable traits in the offspring. It is, however, now generally accepted that except for the effect of chance in sampling, any breeder who practises inbreeding can be almost certain that there will be some deterioration in his livestock, particularly in vigour. It is also very doubtful whether inbreeding can substantially reduce the range of variation in economically important traits as so much of the withinherd and flock variation is due to environmental factors.

Inbreeding is, of course, still used to fix a specific trait in a particular group of livestock, such as the polled condition in cattle, but it must be used judiciously. Some measure of inbreeding is also implicit in any progeny testing or MOET programme where AI is used to propagate the progeny of the selected sires. Thus, breeding policy in any large-scale progeny testing and AI programme must be continuously reviewed.

After the success of the maize breeders in crossing inbred lines and producing hybrid corn, the application of their methods to livestock production was considered. The production and crossing of inbred lines of poultry has been commercially successful and most of the new breeds that are available in the tropics today, emanating from the large commercial breeders, are hybrids of one kind or another. Efforts are also being made to develop inbred lines of pigs with the objective of producing commercial hybrids.

Line Breeding

Line breeding is the term used to describe the system of inbreeding that ensures that outstanding traits in one ancestor are transmitted to descendants without the undesirable effects normally associated with inbreeding. This is accomplished by ensuring the mating animals are as unrelated to each other as is possible except for their relationship to the outstanding ancestor to which the breeder wishes to line breed his stock. A schematic illustration of line breeding is shown in Fig. 4.12. In tropical cattle breeding perhaps the best-known example of successful line breeding is the use of the outstanding Santa Gertrudis sire 'Monkey' and his sons at the King Ranch, Texas, in the evolution of the Santa Gertrudis breed.

Crossbreeding

When unrelated livestock are mated the system is known as crossbreeding. The progeny of crossbred livestock are heterozygous for those traits that differ in their parents, and the greater the differences between parental traits the greater the degree of heterozygosity in the offspring.

As all crossbred progeny inherit the totality of parental characteristics in more or less the same manner they tend to resemble each other to a greater or lesser degree. A simple example would be the crossbreeding of red and white Shorthorn cattle where all progeny are roan in colour. Also first-cross progeny are usually superior to the inferior parent in productive traits and often to both parents. This phenomenon is known as *heterosis* or *hybrid vigour*. It is probably due to the effect of overdominance, discussed in a previous section, where the heterozygotes are superior in one way or another to both the homozygotes.

The degree of hybrid vigour exhibited depends on the extent to which the characteristics of the parental stock are complementary. In general, the greater the differences in the parental genetic make-up the greater the degree of hybrid vigour, which in productive traits is expressed mainly in terms of improved fertility, viability

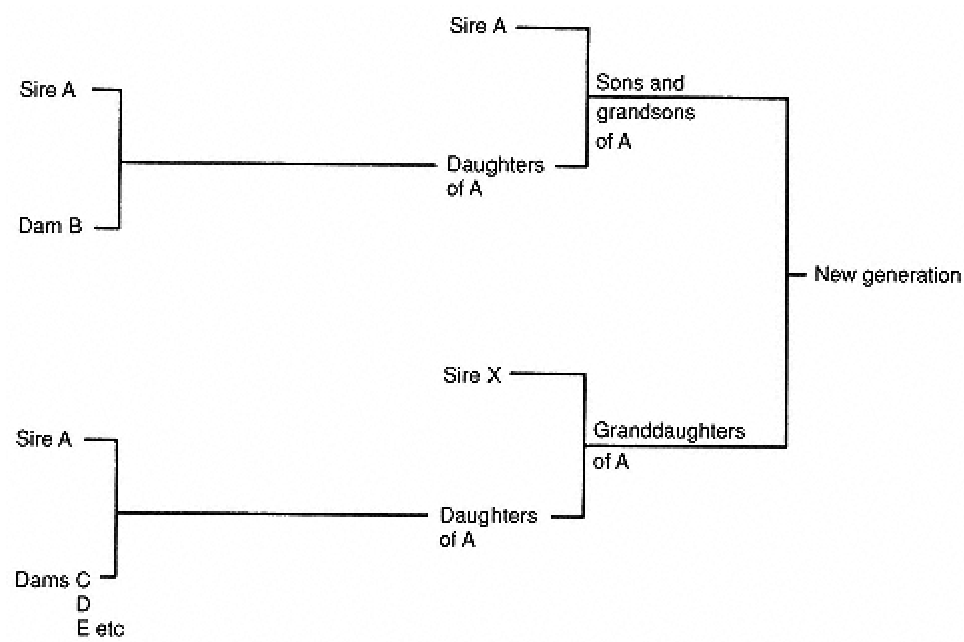


Fig. 4.12
A schematic representation of linebreeding.
(Source: Mahadevan, 1970.)

and general thriftiness. It is also possible that the degree of heterosis depends upon the level of the environment as Barlow (1981), reviewing the literature on geneticenvironmental interactions, has suggested that the more stressful the environment the greater the heterosis. Hybrid vigour disappears very rapidly when hybrids are mated *inter se* so that new parental stock is continuously required if the livestock owner wishes to exploit hybrid vigour to the utmost.

Crossbreeding, where it has been practicable, has been a constant feature associated with the introduction of exotic livestock into the tropics. In the past, crossbreeding has not been utilized to any extent to improve the productivity of tropical livestock, and where it has been successfully used it has been invariably accompanied by improvements in management and modifications of environmental conditions. One example is the development of a modern poultry industry in most tropical countries that depends upon the importation of hybrid chicks from the temperate zone and the adoption of temperate-zone managerial methods. This is of course possible in the poultry industry as the benefitcost ratio is usually favourable. It may also be possible in the pig industry, as the very rapid development of pig production in some countries in Southeast Asia appears to demonstrate. However, the situation with regard to ruminant livestock has been different. Although the crossbreeding of dairy cattle has been practised in many tropical countries for a long time on an experimental or pilot-scale basis, it is only very recently that crossbreeding has been used on a very extensive scale in India and other countries. Similarly the crossbreeding of beef cattle is now being advocated in the tropical Americas and of sheep for improved wool production in Africa, Western Asia and South Asia.

Crossbreeding can be useful in three ways to livestock owners in the tropics. First, it can be used for breed replacement purposes. Indigenous, low-producing livestock can be upgraded by continually backcrossing them to more highly productive, introduced stock. Secondly, an attempt can be made to produce new synthetic breeds by crossbreeding indigenous with introduced livestock, mating *inter se* and then selecting the type of animal required. Thirdly, advantage can be taken of both hybrid vigour and complementarity using some form of systematic crossbreeding between two or more breeds of indigenous and/or introduced breeds.

Upgrading

This is the method of choice when a livestock owner wishes to change radically the characteristics of his animals. A schematic illustration of the upgrading of indigenous (I) stock by imported exotic stock (E) is shown in Fig. 4.13. Males of the exotic type are mated generation after generation to indigenous and crossbred females. It will be seen that by the F4 generation the livestock are almost entirely of the exotic breed type. In any breed 'grade' animals can be upgraded to 'purebreds' using this technique.

There are situations in which it is most advantageous to use only F1 males for upgrading purposes. Only 50% of maximum heterozygosity is achieved, but by using this technique genes from the exotic breed can be incorporated in the indigenous breed with minimum disturbance of existing conditions. A relatively small number of outstanding indigenous female stock can be selected, assembled at a centre and mated to introduced males or inseminated with imported semen. The F1 bulls produced are then distributed for breeding purposes, generation after

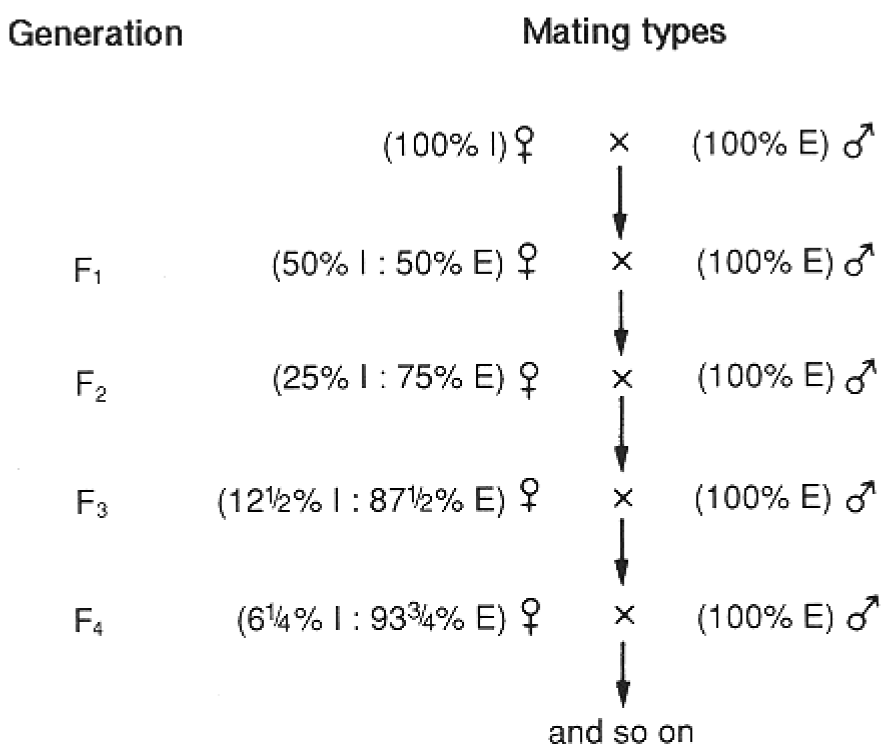


Fig. 4.13
A schematic representation of upgrading.

generation, throughout the indigenous breed area, ensuring a slow upgrading of the indigenous livestock.

Developing New, Synthetic Breeds

The development of a new breed may be accomplished by the crossbreeding of two breeds of a specific type of livestock, followed by back-crossing one way or the other to attain the planned cross of the parent breeds. At this stage the crossbreds must be mated *inter se* followed by intense selection among their progeny for the type of animal required. More complex synthetic breeds can be produced. The easiest method of establishing a synthetic breed from three parent breeds is to mate F1 individuals produced from crossing two of the breeds to purebreds of the third breed and to use the resulting generation as the foundation herd. Some details of new synthetic breeds are provided elsewhere.

The Exploitation of Hybrid Vigour by Crossbreeding Systems

Two or more breeds of a specific type of livestock may be used in a planned crossbreeding programme in order to exploit the phenomenon of hybrid vigour. The simplest system is one in which two parent breeds are used to produce an F1 population; used commercially but not for breeding. Two purebred parent breeds have to be retained and the cross repeated in each generation. This system maximizes heterosis and is used by pig producers in both temperate and tropical countries. A more complex system involves the rotational use of sires of one breed during one generation followed by the use of sires of a second breed during the next generation, and so on. A schematic illustration of such a system is shown in Fig. 4.14, A and B representing the two breeds used in this programme. Any number of breeds could be included in such a programme, but it is generally agreed that nothing is to be gained by using more than three breeds.

The value of a rotational crossbreeding system compared with a system that attempts to develop a new breed is that the former may be more

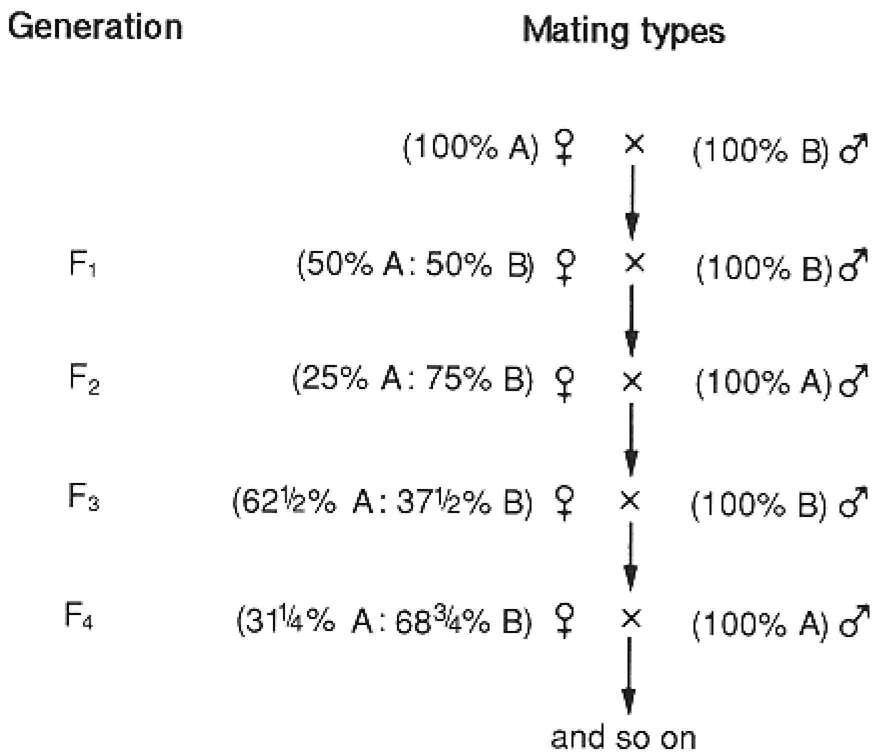


Fig. 4.14
A schematic representation of a criss-cross breeding system designed to exploit hybrid vigour.

productive because it exploits hybrid vigour. Genetically this is because rotational crossbreeding inhibits gene recombination. The disadvantage of rotational crossbreeding is that the breeder must have access to sires or semen from two or more breeds, thus complicating management compared with the use of one breed. It is very difficult to operate rotational crossbreeding under smallholder conditions and so the use of this breeding system in the tropics is likely to be confined to large holdings. On the latter, crossbreeding may have two additional advantages. First, increases in productivity may be achieved with little increase in economic inputs and secondly a slowly increasing impact of inbreeding depression in established breeds may be countered by the introduction of a crossbreeding programme.

Genetic Engineering.

Genetic engineering or recombinant DNA technology can now be used to modify the function of animals or even to produce new types of animals. It could be considered as a final triumph of man over other species, or as a Pandora's box, opened at man's peril.

The germ line of an animal can be manipulated to add a gene, known as a *transgene*, or to modify or destroy genes. A number of different methods have been used (Wilmut & Clark, 1991), but to date the results have been of mixed value. The percentage of positive results has been less than 1%, many transgenic animals have had poor survival rates and transgenic animals need extensive screening and evaluation before they can be manipulated and utilized under farming conditions.

The possibilities are infinite but the most important of those being investigated and developed at the present time are:

• *Improvements in productivity*. Early efforts were concentrated on breeding animals with improved growth rates. The overall results have been disappointing, with serious health and welfare problems. Present efforts are concentrated on improvements in feed conversion efficiency, the ratio of lean to fat meat and disease resistance.

• *Production of pharmaceuticals (pharming)*. The primary aim has been to use transgenic animals to produce valuable recombinant proteins of pharmaceutical value. The strategy has been to divert the synthesis of protein to the secretory epithelial cells of the mammary glands of the animal and then harvest the product from the milk. Several valuable pharmaceuticals are being produced in this manner. A major advantage is that the productive source is free of human infective agents.

• *Non-human organ donors*. Human genes that control the production of natural complement activity regulators (NCAR) have been inserted into the genome of the pig. It is proposed that such transgenic pigs can be used to provide vital organs, such as hearts, that can be transplanted by surgery to humans, as such organs appear to be protected from hyperacute rejection. No such experiments have yet been attempted and the moral issues are under discussion and are unresolved.

• *Production of vaccines*. It is possible to copy and bulk-up genetic material by introducing it into bacteria and then to induce the bacteria to reproduce very rapidly. The technique is known as *gene cloning*. The product can be formulated into a vaccine (Quirke & Schmid, 1988).

It is unlikely that recombinant DNA technology in general, except for the production of vaccines, is likely to have any immediate impact on tropical animal production. Studies on disease resistance and new types of vaccine against virus diseases could, however, be of major importance in the long term.

If livestock genes are to be manipulated it is obviously necessary to produce accurate maps of livestock genomes. Those for cattle are most advanced with two centres, one in the United States and the other in the European Union (France) providing information. Bulfield (1996) provides some detailed information on genome mapping. Also of importance is the detailing of *markers* for quantitative genes that indicate proximity to other genes that may be of interest.

Disease Resistance

No genes confer universal resistance to disease or to parasites, however the immune system is regulated by groups of genes that not only control innate immunity but can also alter the specificity and quality of acquired immunity. Identification of these groups of genes and of disease resistant livestock promises major benefits, particularly in the tropics (Owen & Axford, 1991). There is a special interest in mapping the genome of trypanotolerant breeds of cattle, such as the N'Dama, with the possibility of finding the genes responsible for trypanotolerance. If the genes that control trypanotolerence were isolated they could possibly be introduced into non-tolerent zebu breeds of cattle.

Breeding Livestock for Tropical Environments

Efforts to breed productive livestock for tropical and subtropical environments have evolved in a cyclic manner.

In the early days of European discovery and colonization many types of livestock were imported into the tropics. The majority died leaving no purebred offspring but in some regions there were survivors and acclimatized types gradually evolved. The import, from AD 1493 onwards of livestock into the Americas by the Spanish, provides an illustration of what could occur. Cattle, the most important of the imported species, rapidly multiplied in the uplands of Mexico and South America (Rouse, 1977), but in climatically adverse tropical regions their mortality was very high. As a consequence, some 400 years later, towards the end of the nineteenth century, a number of *criollo* breeds or breed types had evolved that were not very productive but were acclimatized to their varied environments. In general, however, the import of temperate-type livestock, especially ruminants, into tropical countries in Africa and Asia has been a disaster. There were some transfers of ruminant livestock from one tropical country to another that were successful. Particularly that of different breeds of cattle from South Asia to Brazil and to a number of tropical European colonies.

During the first third of the twentieth century most colonial powers reversed their previous livestock import policies and attempted to develop indigenous breeds in their tropical territories, particularly cattle breeds. During this period the first large-scale attempts were made to catalogue indigenous tropical breeds and to record their productivity.

After World War II, with an overall growth in human population and with most tropical countries becoming independent, an attempt to improve the productivity of tropical livestock was orchestrated by national and international development agencies. They concluded that efforts to improve productivity by selection within tropical breeds was too slow a procedure and that new methods were required. These included: attempts to improve the environment so that productive temperate-type breeds could be used, a method generally adopted for large-scale pig and poultry production and for dairy production in mainly oil-rich, subtropical, Western Asian countries; crossbreeding schemes using varied methodologies to incorporate the high productivity of temperate-type dairy and beef cattle, sheep and goats, with the hardiness of indigenous breeds; and the production of synthetic breeds of ruminants, mainly cattle, that would be reasonably productive in a tropical environment.

Some progress has undoubtedly been made, particularly in cattle production, but as will be seen from the milk production data in Table 4.7, it has been limited, uneven in incidence and has occurred mainly in the Americas, Asia and the Oceanic tropics. Payne & Hodges (1997) reviewing the progress of cattle breeding in the tropics during the period from 1950 to 1990, concluded that although some progress had been made it is now essential to consider new and possibly more appropriate breeding strategies.

Major difficulties in the planning of appropriate breeding policies for the tropics are that:

- There are serious climatic and endemic disease differences between continental and oceanic regions and the high altitude areas and lowlands within continents.
- There are important differences within continents and between regions in the scale, type and organization of livestock enterprises.
- There are very large differences in knowledge and access to appropriate resources of nomadic, subsistence, smallholders and large-scale livestock owners.
- There are limited scientific data on major genetic differences in the productive characteristics of tropical breeds.

Payne & Hodges (1997) proposed that any cattle breeding strategy in the tropics should include:

Table 4.7 Average milk production of dairy cattle in the tropics in 1950 and 1990. (*Sources*: FAO, 1967 and FAO, 1991.)

Continent	Country	Average milk yield (kg per annum) 19481952a	1990
Managed in tropical/subtropical climates			
Africa	Kenya	1130b	450
	Mali	534	200
	Niger	220	200
	Sudan	328	501
	Uganda	234	350
	Zimbabwe	849	1687
Americas	Brazil	366	769
	Colombia	462	1029
	Trinidad	1406	1500
	Venezuela	722	1265
Asia	India	166	905
	Indonesia	1931	1017
	Malaysiac	356	637
	Pakistan	335	1152
Australia	Fiji	883	1712
Managed in temperate climates			
Americas	United States	2389	6711
Australia	New Zealand	2620	3412
Europe	United Kingdom	2723	5213

a Five-year average.
b Improved stock only.

c West Malaysia only.

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• A plan that can be properly implemented within the scope of local resources.

• Objectives that match the values and expectations of the livestock owners.

• A 'package' that incorporates management, feeding, health, marketing, and extension support.

• The provision of improvements in productivity that are evident and meaningful for the livestock owners.

It was also suggested by Payne & Hodges (1997) that as the majority of tropical cattle are owned by smallholders, particularly in Africa and Asia, field recording and the field use of AI are often bedevilled by problems. Under these circumstances recording and selection can most easily and effectively be conducted in livestock stations, within which a specific proportion of the field livestock population can be recorded.

To summarize, livestock breeding policies based on selection within indigenous breeds, import substitution by both temperate and tropical breeds, crossbreeding temperate and tropical breeds and the formation of new, synthetic breeds have been advocated and practised in tropical and subtropical countries with limited success. On account of the multiplicity of sub-climates, livestock breeds and managerial practices it is likely that some, if not all, of those breeding policies will continue to be used. Experience has, however, suggested some changes in the methodologies employed in order to improve future breeding plans.

The Use of Indigenous Breeds

The advantages of using indigenous breeds are that they are readily available, acclimatized to the local environment and probably possess desirable genetic traits associated with acclimatization. Also genetic variance within these breeds appears to be of the same order as in temperate-type breeds. Their major disadvantage is that past selection must have been primarily for survival under extreme stress conditions and that such a selection is likely to have been at the expense of production traits. Thus it is likely that any selection for increased productivity, even under improved managerial and feeding conditions, is likely to be a lengthy process. A further difficulty is that the field recording required for selection purposes is often difficult to accomplish in many countries with indigenous tropical breeds.

We suggest that the use of indigenous breeds is most likely to be successful where:

(1) Stress on all livestock is very severe but where it would be uneconomic to rapidly improve the environmental conditions, as in many arid and semi-arid regions.

(2) The indigenous livestock possess some specific, adaptive trait, such as the tolerance of trypanosomosis in N'Dama and West African Shorthorn breeds of cattle or the resistance to helminths, demonstrated by some breeds of tropical sheep.

Some examples of where the utilization of indigenous breeds is at present rational and economically justified and where every effort should be made to improve their productivity are:

• Zebu cattle breeds such as the Boran in East Africa and the Maure and Shuwa in West Africa for meat production in semi-arid areas.

• Sanga breeds of cattle such as the Mashona, Tuli and Africander for meat production in Central and Southern Africa.

• N'Dama and West African Shorthorn cattle for tsetse-infested regions of Africa.

• A *Bos (bibos)* breed such as the Bali for work and meat production in the humid areas of Southeast Asia.

• Specific water buffalo breeds for milk production in South and Southeast Asia.

• Camels for meat production in the arid areas of Africa and South and Western Asia.

- Desert-type sheep and goats for meat and hide production in the semi-arid regions of Africa and South and Western Asia.

Apart from improving the productivity of indigenous breeds, where and when the task is economically justified, it is vitally important that at least a limited number of individuals in all indigenous breeds be conserved in some manner as a future source of genetic variance. This subject is discussed in some detail in Chapter 5.

Unfortunately, there has already been a serious loss of indigenous breed traits in some tropical and subtropical regions due to continuous upgrading of the indigenous breeds using exotic livestock. It is a major problem in Central and South America and in Western and Southeast Asia. In Central and South America many criollo and criollo cattle breeds have almost disappeared due to upgrading using either temperate-type and/or zebu breeds, whilst experimental work has shown that in some environments criollo crossbreeds are superior in productivity to the upgraded cattle. In Western Asia and Southeast Asia indigenous cattle are being upgraded in such numbers and so quickly that there is a real danger that many useful genetic traits will be lost.

The Importation and Use of Exotic Breeds (Import Substitution)

The present distribution of the world's livestock is almost an historical accident. Primarily, it is the result of the movement of human populations with their accompanying livestock and not the result of a deliberate breeding of specific types of livestock for specific environments. The latter process has only occurred within historical times. If, for example, the northern regions of South America had been colonized by South Asians and not by Europeans, then it is likely that the water buffalo would now be of major importance in the Orinoco and Amazon river basins. Instead, the descendants of the European colonizers have only, in the twentieth century, realized the potential value of water buffaloes in these environments.

When the importation of exotic breeds into the tropics is discussed, it is usually in terms of importation from temperate climates. As noted previously, such imports have often been a disaster and we would only advocate them under special circumstances when adequate managerial, feeding and disease prevention measures are insured. It is, however, necessary to consider the possibilities of importing livestock from one tropical country into another. The advantages are that the imported livestock are likely to be acclimatized and may possess desirable traits unavailable in the indigenous livestock.

A major disadvantage of import substitution is that it is inevitably expensive. It is difficult to increase rapidly the number of imported animals, though fertilized embryos can now be imported and incubated in indigenous females. If animals of temperate-type breeds are imported, amelioration of tropical conditions and/or acclimatization may be both time-consuming and expensive. If animals of a tropical-type breed are imported special precautions may have to be taken with regard to disease.

The importation of temperate-type breeds is most likely to be successful where:

(1) Climatic, nutritional and disease stresses are low such as in some upland areas of tropical Africa, Asia and the Americas and on some oceanic tropical islands; or

(2) The economic situation is such that livestock owners can afford to manage their animals in controlled environments; this is the position of large-scale pig and poultry producers in many areas of the tropics and of milk-producers in some oil-rich West Asian states.

The situation is different for the importations of tropical livestock. These are most likely to be useful and successful where:

(1) No indigenous breeds are available to exploit a specific environment; examples are the importation of water buffalo from South Asia to swamp and seasonally flooded regions of tropical Africa and the Americas and zebu cattle from South Asia to the semiarid tropical and subtropical regions of Africa and the Americas.

(2) A far more productive exotic than any indigenous breed that can easily acclimatize is

introduced; in general these introductions such as the Sahiwal from India to East Africa, have not resulted in large-scale substitution but in widespread crossbreeding.

Some examples where import substitution of livestock can at present be economically justified are:

• Temperate-type breeds of livestock in the montane areas of Africa, the Americas and Asia where disease is controlled and adequate feed and managerial services are available.

• Temperate-type dairy cattle, pigs and poultry managed under climatically controlled conditions in those tropical countries where such managerial conditions are economic.

• Zebu beef breeds such as the Boran of East Africa introduced to the Americas and Australia as soon as a suitable quarantine regime can be organized.

• Water buffaloes from South Asia introduced into the Guinea coast of Africa, the Congo basin and the *sudd* in southern Sudan and into additional seasonally flooded regions in the Americas.

• Temperate-type sheep in the montane areas of South America.

Crossbreeding and/or Upgrading of Indigenous Breeds

The merits of crossbreeding are that the breeder can hope to combine desirable traits from the parental stocks and exploit hybrid vigour. The latter, mainly expressed in traits that are not highly inherited such as vigour and fertility, is possibly higher under stress conditions, is expressed to a greater extent in females than in males and usually declines with age.

A disadvantage of all crossbreeding programmes is that two or more different breeds of livestock are required and this can complicate management and increase costs, particularly in programmes for large ruminant livestock. The most suitable practice in such schemes is to use indigenous females and import males or their semen. The major disadvantage, however, in crossbreeding larger ruminants, particularly dairy cattle, is that it is difficult to decide what procedure to follow after the production of the first (F1) generation. The problem has been well illustrated by Syrstad (1989) who used 42 sets of crossbred cattle data from 12 different tropical and subtropical countries (Table 4.8). It will be seen from Table 4.8 that upgrading tropical- by temperate-type cattle beyond the 50% level

Table 4.8 The effect of different levels of crossbreeding between temperate- and tropical-type cattle on some production indexes. (*Source*: Syrstad, 1989.)

Proportion of *Bos taurus* genes in the crossbred	Production indexes			
	Age at first calving (months)	Milk yield (kg)	Lactation length (days)	Calving interval (days)
0	42.3	1069	274	452
1/8	41.1	1456	291	441
1/4	37.3	1525	285	444
3/8	36.1	1614	295	433
1/2 (F1)	31.9	2056	306	423
5/8	33.6	2042	296	424
3/4	33.8	2097	301	444
7/8	34.5	2021	301	450
1	32.6	2122	322	459
1/2 (F2)	34.8	1557	292	441

provides virtually no improvement in milk production and three other production indexes and that interbreeding F1 animals to provide an F2 generation leads to a general decline in productivity, which in the case of milk yield can be as high as 2025%.

There is no major problem if the F1 generation is terminal and not used for breeding purposes, as is the case in many pig and poultry and some ruminant meat producing livestock schemes. A major problem exists, however, in dairy cattle breeding programmes.

Several solutions have been proposed. One is the use of three breeds, one indigenous and two exotic, in a rotational breeding system. Such a system does not, however, maintain productivity at the F1 level, further complicates and increases the cost of management and is not an option for the small farmer. It can only be practised under large-scale farming conditions. A solution described by Madalena (1993), and said to be already operational in Brazil, is a form of stratification comprising two types of livestock holding. One type is the large-scale ranch on which approximately 60% of the zebu breeding stock would be inseminated using temperate-type dairy cattle semen (Holstein-Friesian for preference) in order to produce F1 heifers. The other would be smaller scale specialist dairy farms to whom the F1 heifers would be sold. These farms would continuously purchase replacement F1 heifers from the ranch. A solution proposed by Payne & Hodges (1997) would be more suitable for small farmers; it is that only F1 bulls or semen should be used on the indigenous stock, so that the percentage of exotic genes in the indigenous cattle would never increase beyond the 50% level. An advantage of this solution is that if for some reason AI cannot be used in the field there would be no need to import and use temperate-type bulls that are often difficult and expensive to maintain in a healthy condition in many tropical climates. A disadvantage, however, would be that a substantial part of the effect of heterosis would be lost and average productivity would be less than that of F1 stock. Recent developments in biotechnology suggest that at some future date it may be possible to clone F1 dairy cattle in order to maintain productivity.

It can be stated, without hesitation, that livestock crossbreeding schemes can lead to an immediate improvement in livestock productivity in many tropical and subtropical countries, but the practical difficulties involved in large ruminant schemes are formidable. They are likely to be most successful in countries where the necessary infrastructure and managerial assistance can be well organized by governments, co-operatives or private enterprise. Apart from crossbreeding schemes for poultry and pigs and possibly other small stock, that can be conducted under controlled conditions in tropical countries, regions where the crossbreeding of large ruminants is likely to be successful are:

• Central and South America where experimental work has already demonstrated the value of cattle crossbreds and where in some regions temperate-type breeds have been unable to sustain their number (Vaccaro, 1990).

• South Asia where crossbreeding for milk production is being conducted and evaluated on a very large scale.

• Southeast Asia where crossbred dairy cattle are being imported on a large scale and crossbreds between temperate-type beef breeds and indigenous *Bos (Bibos)* breeds are being evaluated.

• East Africa where Sahiwal are being crossed with temperate-type breeds (Mackinnon *et al*., 1996).

• West Africa where various crossbreds between the N'Dama and West African Shorthorn breeds and zebu breeds are being evaluated in tsetse infested areas.

In those regions of the tropics, such as upland areas, where temperate-type livestock can thrive and are required, an upgrading programme is more advantageous than mass importation. It is not only more economic, as large numbers of indigenous livestock can be upgraded rapidly and inexpensively (see Fig. 4.12) using a limited number of imported bulls or AI, but it has the great advantage that attempts can be made at the same time to improve the managerial standards of livestock owners.

The Development of New Synthetic Breeds

Where managerial and other difficulties preclude the use of crossbred livestock and livestock owners do not wish to completely upgrade their animals and substitute one breed for another, but they would like to utilize animals intermediate in type, the development of new synthetic breeds is indicated. The difficulties are that such action requires a long-term and large-scale breeding programme, employing highly trained and competent personnel that can only be contemplated by governments, international agencies or very large private organizations.

During the twentieth century many attempts have been, and are being, made to develop new breeds, particularly of beef and dairy cattle. Private breeders of beef cattle have been particularly active in North America and new breeds acclimatized to the drier tropics such as the *Beefmaster*, *Brangus*, *Charbray* and *Santa Gertrudis* have been developed. Plans to develop in North America dairy breeds acclimatized to the tropics were abandoned, but such plans have been somewhat more successful in Australia, Brazil, India, Jamaica and Tanzania. In Australia two acclimatized breeds, the *Australian Friesian Sahiwal* and the *Australian Milking Zebu* have been developed, in Brazil the *Pitangueiras,* in India the *Karan Fries, Karan Swiss* and *Sunandini*, in Jamaica the *Jamaica Hope* and in Tanzania the *Mpwapwa*. All these new breeds, with the exception of the Mpwapwa that is managed in a particularly stressful climate, produce 20004000 kg of milk per lactation (Payne & Hodges, 1997). It is not yet known whether any of these new breeds will be accepted as major tropical milking breeds or whether they will ultimately disappear.

Though there is now some choice of new, acclimatized beef and dairy cattle breeds, productive breeds acclimatized to specific regions such as the tsetse fly infested areas of Africa are still required as are new breeds of other livestock. We suggest that new breeds are urgently required of:

- Sheep bred for meat production in the humid tropics.
- Dairy-type goats suitable for use by subsistence farmers in either the humid or the arid tropics.
- Beef-type water buffaloes for use in very humid regions.

As it is unlikely that these new breeds will be developed by private livestock owners we suggest that the Consultative Group on International Agricultural Research (CGIAR) could consider the organization of such breeding programmes.

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5
Conservation of Farm Animal Genetic Resources

Background and Setting.

The tropics are repositories of a broad range of domestic animal diversity. Most of the world's 40 or so commonest domestic species and a majority of the more than 4500 breeds and types known to exist (Table 5.1) are found here. Africa typifies this diversity (Fig. 5.1). All major species of ruminants (cattle, goats, sheep and buffaloes), pseudorumimants (one-humped camel), monogastric quadrupeds (horse, donkey, pig) and several species of poultry (domestic fowl, guinea fowl, Muscovy duck, pigeon) are represented. Many minor or potential domestic species are also present (cane rat, grass cutter, antelope) as are non-conventional microlivestock (snail, earthworm). The wild progenitors of some domestic species (Nubian and Somali wild asses, guinea fowl) are indigenous to Africa and many near relatives of the present domesticates, such as the Nubian ibex and Barbary sheep, are African natives.

Africa's 600 million ruminants, 18 million equines, 12 million camels, 12 million pigs and 800 million poultry are a genetic resource of incalculable value in support of human life. Some 420 breeds, not including poultry, have been named but there are certainly more that have not yet been identified or described. African livestock breeds have developed in response to several factors, including a wide range of climates, intense environmental stresses, isolation and the demands of man.

The domestic animal genetic resources of Africa have been described briefly and partially at species level (Mason & Maule, 1960; Wilson. 1991), either for the continent or as part of a more global treatment (Maule, 1990). A few African breeds or breed groups (FAO, 1980a, 1980b, 1988, 1992b) have been studied at varying levels of detail. A much larger number has been accorded less attention (Epstein, 1971). Most, however, have not been studied at all and little is known about them other than their name and their general area of distribution (Mason, 1996). Some African breeds will disappear, and some indeed have already done so, before they could be described (Hodges, 1992). Characterization and conservation of this enormous reservoir of animal wealth are major tasks in need of urgent action.

The Need for Characterization

Realization of the need for conservation of domestic animal diversity has come late to the world scene. It has received, and still receives, much less attention than that given to plant and wild animal resources. Some awareness has, however, been created in recent years of the state of the world's domestic animal resources and there is now belated concern about their fate. The extent of this varies from passive awareness, through preservation, efforts at identification and characterization, to active *in situ* and *ex situ* conservation (FAO, 1987, 1992a)

All living organisms result from natural selection and have developed in response to stresses and pressures from their environment. Natural

Table 5.1 Number of breeds of farm animals in various regions of the world. (*Source*: Scherf, 1995.)

Domestic species	Region						Total breeds
	Africa	Asia/Pacific	Europe	Latin America/ Caribbean	Near East	North America	
Buffalo	2	57	2	3	7		71
Cattlea	120	196	305	62	62	48	793
Donkey	6	17	16	5	28	5	77
Goat	34	126	113	13	55	10	351
Horse	31	72	185	24	31	41	384
One-humped camelb	12	14		12	31		69
Pig	13	157	129	24	2	28	353
Sheep	73	226	42	23	129	47	830
Domestic fowl	57	72	406	35	26	10	606
Duckc	10	23	35	6	2	n.a.	76
Goose	5	8	n.a.	5	n.a.	1	19
Turkey	6	5	14	4	1	1	31

a Includes six yak breeds in Asia.
b Includes Bactrian camel where appropriate and is limited to South American Camelidae in Latin America.
c Includes common and Muscovy types.

selection eliminates the unfit. Selection might be for tolerance to drought, to a fluctuating feed supply or to resistance to disease. Over a relatively short period of less than 8000 years in the case of most of his livestock, man has influenced the selection process and moulded them to his needs. The outcome is the current array of species and breeds.

The main preoccupation of livestock owners in the often harsh environments of the tropics in the past has been to maintain and reinforce natural survival strategies. It is thus not surprising that many tropical domestic animals do not produce large quantities of milk or grow very rapidly. These facts are not synonymous with poor productivity. Production has been, and continues to be, adapted to the environment. It is these adaptive qualities, acquired over hundreds or perhaps thousands of generations, that need to be conserved.

Little is known of the genetic relationships of many domestic livestock in the tropics and the differences between them. Phenotypic or physical differences might not by themselves be indicative of genetic ones. On the other hand, animals apparently of one type can be quite different. Problems may arise from this uncertainty, especially when assigning conservation priorities.

Recent DNA research on N'Dama cattle in West Africa (Bradley *et al*., 1993a, 1993b) has shown animals in Guinea are pure *Bos taurus*. Physically similar cattle in The Gambia have DNA sequences akin to *Bos indicus*. A clear case has been made for introgression of Maure and Gobra zebu genes into the northern populations of N'Dama (Fig. 5.2). Guinean and Gambian cattle may thus differ in tolerance of trypanosomosis, a trait that allows West African *Bos taurus* to live and produce in tsetse-infested areas where most *Bos indicus* cannot. An opposite case occurs in northeastern Africa where a group of physically dissimilar sheep (Fig. 5.3) is classed uniquely as Sudan Desert. No genetic work has been done to find out if the animals are distinct. They differ in productivity, however, especially in the number of young born per litter (Suleiman & Wilson, 1990).

There is certainly inadequate knowledge of the genetics of tropical domestic livestock. A

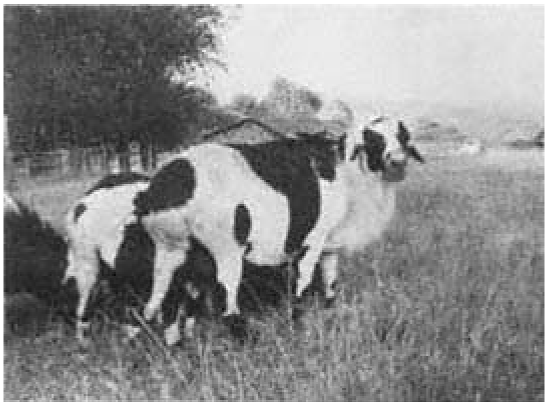
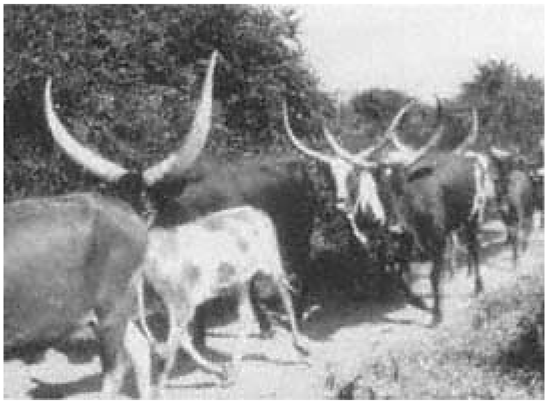


Fig. 5.1
The Rwanda type of East African long-fat-tailed sheep



Ankole cattle of the Sanga group in northwest Tanzania

A Sudanese Riding donkey from Darfur

A pied camel from Niger are important African species and breeds and contribute to the genetic diversity of its domestic livestock.

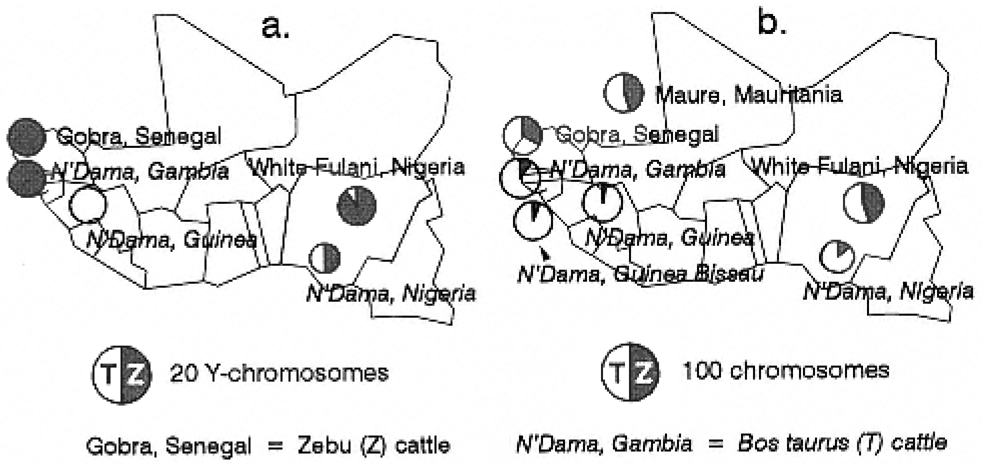


Fig. 5.2
Zebu Y-chromosome (a) and autosomal introgression (b) into indigenous *Bos taurus* cattle in West Africa.

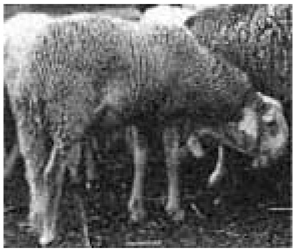
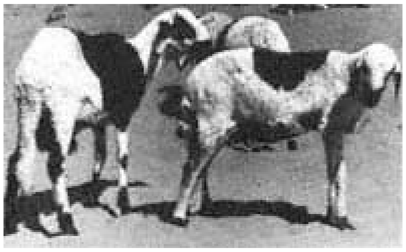
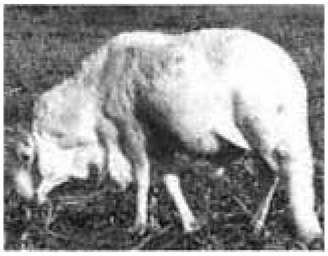


Fig. 5.3
Three tribal or subtypes of 'Sudan Desert' sheep showing phenotypic diversity within a 'breed': Shugor ram



Dubasi ram and ewe



Watish ram.

survey in the early 1990s (Scherf, 1995) resulted in detailed information being gathered on only about 40% of the known breeds. There are sure to be many other 'breeds'in the sense of isolated and genetically differentiated populations. These have developed over long periods to cope with particular and often intense combinations of disease, nutritional and climatic stresses. The problem is not that there is very little information on population numbers, productive performance and genetic make-up for most named breeds. It is rather that nothing at all is known about the great majority still under traditional ownership in populated and accessible as well as in remote and isolated parts of the world.

There is an urgent need to collect sound data on tropical domestic animals and to compile a complete inventory of breeds and genetically distinct populations. A rational assessment of the value of, and the risk to, these genetic resources must then be made, so that the activities and priorities required for their better use and maintenance can be firmly established.

The South Asian region, comprising India, Pakistan, Sri Lanka, Bangladesh, Nepal and Bhutan, provides examples of countries which have populations of animals known to be repositories of diversity and adaptability, or to be at risk. It is not clear, however, that these countries and their breeds are indeed the most important or most endangered and therefore deserving the highest priority for action. With current knowledge, the danger is that decisions based on such limited and probably unrepresentative but well-motivated publicity will be taken merely because of lack of information on more pressing cases.

The Need for Conservation

Domestic animal diversity is part of the earth's heritage. The genetic constitution of an animal determines its response to all aspects of the production system. This includes the whole range and combination of stresses but particularly those related to climate, nutrition and disease. This tenet must be accepted to achieve sustainable agriculture, to obtain production and productivity increases, and to manipulate product quality efficiently.

The result of natural and man-assisted selection is a gene pool for each domestic species that has been redistributed such that about half the genetic differences are unique to any one breed while the other half is common to all breed resources. Use of this between- and within-breed genetic diversity, preferably in readily available forms, is an essential hedge against future unforeseen human nutritional requirements, disease problems, production technologies and other substantial changes to one or other production environment.

The single development and universal use of just one or a very few high-input/high-output genetic types, for some of the major animal species, has been increasingly emphasized in recent years. This is particularly so for cattle, pigs and poultry where aggressive marketing has had a major influence on breed structure not only in the tropics but in the world as whole. There is a need to develop and correctly use diversity to increase production and productivity, to achieve sustainable agricultural systems and, where required, to meet demands for specific product types. Resources currently represented by very few animals or being dislodged by breed replacement strategies must be monitored. Above all, perhaps, there is a need to conserve assets not currently in demand but for which future demand cannot be predicted.

The Current Situation

It has been argued that economically useful breeds will survive due to the effects of market forces (Wilkes, 1991). The obvious opposite point of view is that breeds with no apparent current utility may be repositories of genes and traits that will be needed in the future (Alderson, 1990). In the tropics, where at least 95% of all domestic animals are indigenous and often considered to be of 'poor' genetic merit because they do not produce vast quantities of a single product, the 'economically useful' argument is spurious. Rapid changes in domestic animal diversity have resulted largely from the increasing sophistication of breeding programmes and commercialization of animal production. Developments in artificial insemination, embryo transfer, and other aspects of biotechnology have allowed a limited number of breeds to gain, very quickly, a dominant position in livestock production.

As a result, other breeds have been consigned to minority roles or to extinction. Modern inputs, often not available in developing tropical countries, are needed to modify the environment if engineered breeds are to produce to their potential. Conversely, only minor improvements may be needed to generate productivity increases in native and adapted livestock.

The rate at which extinction of genetic resources is occurring appears to be accelerating (Fig. 5.4) A number of old and new factors is implicated. These resources are for all practical purposes irreplaceable: once lost they are gone forever. A preliminary data bank analysis shows that many domestic animal breedswhich may have taken almost 10 000 years to developare now at high risk of extinction (Scherf, 1995).

Programmes for Conservation of Domestic Animal Diversity

Programmes for conservation and enhancement of animal genetic resources and their diversity need to be established or strengthened to prevent further losses of this important component of man's and the world's heritage (Rege & Baker, 1993) The objective of most extant genetic improvement programmes is exactly the opposite and is designed to adapt animals to a narrowly defined current environment for a chosen production objective. The resulting genetic base is drastically narrowed as uniformity of performance or of appearance is increased and limited characteristics are concentrated to the exclusion of others.

A uniform database for collecting and disseminating data concerning animal populations, the institutions working on them, the research being carried out, and the existence and operation of germ plasm banks needs to be established. Guidance, to countries on the organization and structuring of their national conservation strategies must be provided. Training and information programmes in animal germ plasm conservation will have to be developed.

Interests and views concerning the management of animal genetic resources are very diverse. Commercial enterprises producing genetically engineered animals are little concerned with the future of species or breeds adapted to uncontrolled environments. Those with a supposedly wider view of mankind are concerned with sustainability in a world where resources might, in the future if not now, limit intensive management and high levels of external inputs. Conservation programmes must be able to reconcile these conflicting views and activities. They must have a mechanism for including the perspectives of national programmes, academic researchers, non-governmental organizations, and the breed and production industries.

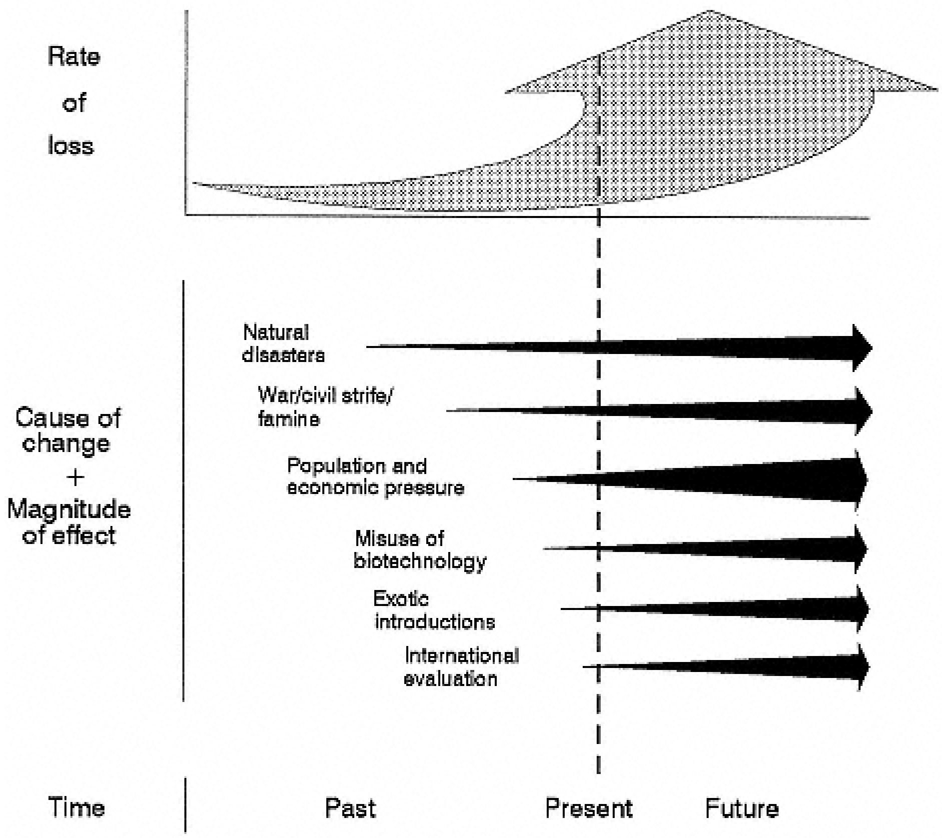


Fig. 5.4
Schematic representation of the loss of domestic animal genetic resources and the factors affecting it.

Identification, description and monitoring of breeds and populations, germ plasm evaluation, molecular mapping and genetic distancing are needed. Identification of all breeds of all species used as food and in agriculture is a basic requirement in view of the current level of risk. All aspects of characterization should be included, from simple phenotypic description, through use, numbers and trends, habitat and production system, and production performance to DNA typing. Diversity in each species and the contribution of each breed to the gene pool are essential criteria for decision-making, maximizing cost-effectiveness and long-term conservation. Genetic distance studies will add objectivity to conservation strategies and early results from these would assist and reduce the real cost of future conservation work.

In situ conservation needs to include active development and use (especially of currently neglected resources), establishment of recording schemes, design of breeding programmes, ecosystem management and creation of sentinel herds in a natural production environment or in animal parks. *In situ* conservation is the 'best' use of indigenous breeds for sustainable agriculture. For introduced or exotic breeds, the factors to be considered are numbers and apparent motivation of importers and exporters, rate and form (live animals, semen, etc.) of migration and extent of crossing with local breeds. Forces leading to displacement of indigenous by exotic breeds must be identified as must official policies relating to this process. Opportunities for making genetic progress and for its wider use must be identified.

Establishment of gene banks comprising DNA, semen and oocytes, embryos and cell lines are some aspects of *ex situ* conservation. National gene banks should be established but need careful planning to ensure initial and long-term success. A long-term 'repository of last resort' might be needed as a continental gene bank under adequate international control.

Indicative Priority Target Areas and Groups

Africa covers a huge area and is an obvious candidate for early conservation activities. The diversity of its domestic animal resources is immense. Livestock are reared in many production systems, some purely pastoral, others being mixed animal and crop enterprises. The system is important as a descriptor because it has a major effect on the use of the animal and thus its products. It would not be realistic to try to describe and classify all these variables in a short period of time. Limited funding, inadequate numbers of staff and the sheer scale of the problem make it necessary to target areas and groups of species and breeds in the first instance (Fig. 5.5, Table 5.2).

Livestock husbandry in South Asia or the Indian sub-continent has been practised from very ancient times. Such a long association with the art of rearing animals and the wide variation in ecological conditions have resulted in the descent and development of livestock species and breeds that exhibit the most extreme variation.

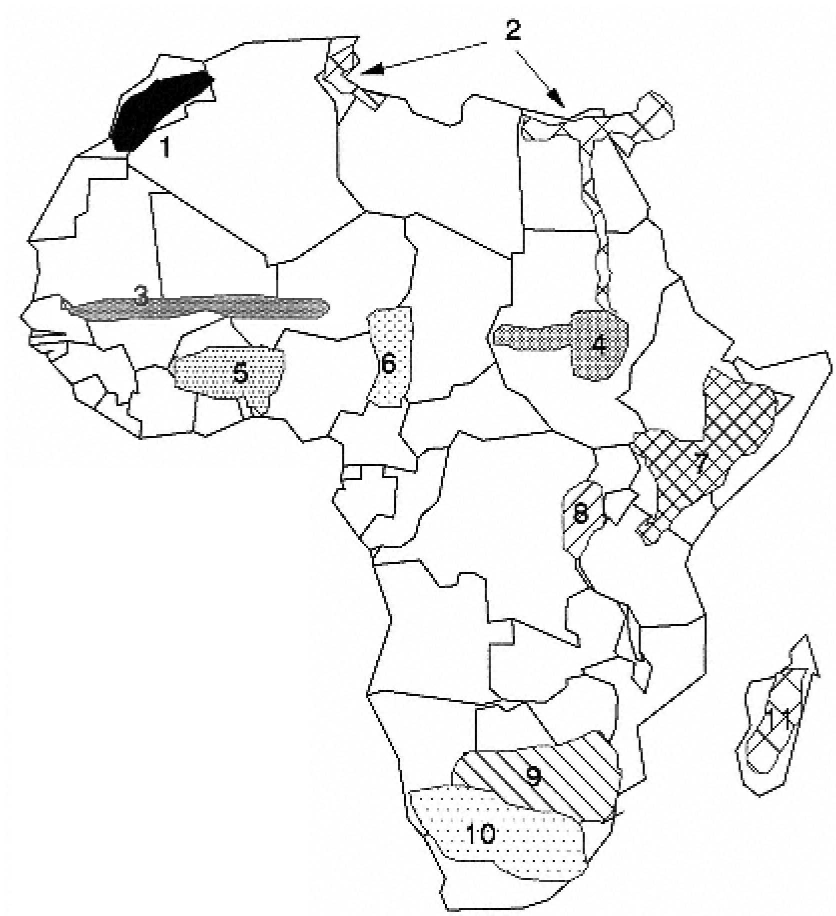


Fig. 5.5
Major centres of diversity of African domestic animal resources.
[1 = Maghrebian mountain and oasis complex; 2 = North African urban and riverine; 3 = West African Sahel arid/semi-arid zone; 4 = Northern Sudan livestock complex; 5 = Humid tsetse-infested West African zone; 6 = Central African relict populations; 7 = East/Northeast African low/medium altitudes;

8 = Central African highlands area; 9 = Southern African Zulu/Ndebele group; 10 = Southern African 'modern' group; 11 = Oceanic islands area.]

The sub-continent is thus a major area of domestic animal diversity and is most important on account of the numbers of species, breeds and animals present. India alone has the largest cattle and buffalo populations in the world, the second largest goat population and probably the third largest population of one-humped camels. It is considered that the world's best breeds of dairy buffaloes, of draught cattle and of carpet wool sheep originated and still produce in this region.

Table 5.2 Target areas, species, breeds and production systems for conservation of African domestic animal resources.

Target areasa	Species/breeds	Production systems
1 Maghreb montane and oasis complex	Cattle: Brune de l'Atlas; Sheep: D'man + Sardi; Goats: Chèvre du Drâ	Montane winter small grains and oasis agriculture
2 North African urban and riverine	Goats: Nubian, Egyptian Beladi + Tunisian Black	Urban scavenging and intensive dairy/feedlot
3 West African Sahel arid/semiarid zone	Cattle: Lyre-horned zebu (Gobra, Maure, Azouak, Sudanese Fulani + Tuareg); Sheep: Macina	Agropastoral transhumance, some flood irrigation
4 Northern Sudan livestock complex	Cattle: Kenana, Butana + Western Baqqara; Sheep: Sudan Desert; Goats: Sudan Desert; Horses: Dongola	Agropastoral and pastoral transhumant and nomadic
5 Humid tsetse-infested West Africa	Cattle: West African *Bos taurus*, Longhorn (N'Dama) and Shorthorn (including Baoulé, Somba + Lagune); Sheep: Djallonké; Goats: West African Dwarf; Pigs; Poultry: Guinea fowl	Smallholder mixed, predominantly perennial trees and tubers
6 Central African relict populations	Cattle: African *Bos taurus* (Namchi, Kapsiki + Kuri); Horses: Logone	Smallholder traditional subsistence and agropastoral
7 East/Northeast African low and medium altitudes	Cattle: Masai, Boran + Somali breeds; Sheep: Red Masai, Afar + Blackhead Somali; Goats: Borana; Camels	Agropastoral and pastoral
8 Central African highlands	Cattle: Lyre-horned Sanga (Bahima + Ankole); Sheep: African long-fat-tailed; Goats: Small East African (Rwanda/Burundi type)	Agropastoral and smallholder coffee/tea/banana
9 Southern African Zulu/Ndebele group	Cattle: Tswana, Tuli + Nkoni (including Landim); Sheep: Sabi + Landim; Goats: Swazi, Ndebele + Tswana	Dryland mixed with coarse grains
10 Southern African 'modern' group	Cattle: Africander; Sheep: Blackhead Persian + derivatives; Goats: Boer; Horses: Basuto pony	Modern large-scale mixed and ranching

11 Oceanic islands	Cattle: Malgache zebu; Pigs; Poultry: Domestic fowl	Mixed smallholder

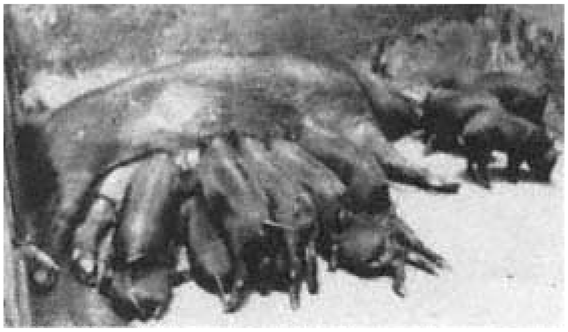
a Number refers to area shown in Fig. 5.5.

The region, as for Africa, has representatives of all the major species of ruminants, pseudorumimants and monogastric quadrupeds. Minor species of livestock in world terms but of great regional economic and cultural importance in the region include the mithun *Bos frontalis*, the yak *Bos grunniens*, the pygmy hog *Sus salvanius* and the Asiatic elephant. The wild progenitors of some domestic species such as the 'arni' (buffalo) and the goat are indigenous to this part of the world. One of the ancestors of domestic poultry, the red jungle fowl *Gallus gallus* is indigenous to India and the neighbouring countries.

In India there are at least 26 well-defined breeds of cattle, 7 of buffaloes, 40 of sheep, 20 of goats, 4 of camels, 6 of horses, 3 of pigs and 18 of poultry (Acharya, 1982). Pakistan, a much smaller country, has 28 breeds of sheep and 25 breeds of goats (Hasnain, 1985). There are other distinct and named breeds of most domestic animal species in Bangladesh, Nepal (Fig. 5.6, Table 5.3) and Sri Lanka. In spite of this identified diversity, however, most animals in the region are truly 'nondescript' in the real sense of the word. They remain undescribed and unrecognized and, worse, indiscriminate crossing of one type with another, or with several others, is rapidly leading to a loss of diversity.

Livestock breeds in the sub-continent have evolved through natural and man-assisted selection and are well adapted to many of the local and stressful environments. Most are resistant to or tolerant of the harsh climate, long migrations,

Fig. 5.6
Hurra pigs scavenging in a Terai town in eastern Nepal



A Pakhribas pig with a litter of 13 young.

Table 5.3 Distribution and management of goat and sheep breeds in Nepal. (*Source*: Wilson, 1997.)

Goats		Sheep		Physiographic region	Altitude (m)	Climate	Management system
Breed	% of total	Breed	% of total				
Chyangra	6.0	Bhanglung	4.0	Mountain	>2500	Cool temperate/ subalpine	Sedentary/ transhumant
Sinhal	35.0	Baruwal	41.0	Mountain	>2500		Transhumant

						Cool temperate/ subalpine	
			22.0	Mid Hill	15002500		Transhumant
						Warm temperate	
Khare	50.0	Kagi	21.0	Lower Hill	3001500	Subtropical	Sedentary
Terai	9.0	Lampuchre	12.0	Terai	<300		Sedentary
						Subtropical/ tropical	

poor nutrition and a lack of drinking water. There have been some limitedlimited in the context of the vast potential that exists in the areaexperiences on evaluation carried out in conjunction with specific animal improvement or crossing programmes. Central and state governments have maintained, and continue to maintain, some stud farms for major breeds. There have also been some attempts at registration of animals of some of the major breeds. Little real use has been made of the data gathered and there has been little central co-ordination of the effort.

There has been much indiscriminate intermating of native populations by traditional owners for perceived short-term gains and 'upgrading' and 'improvement' of indigenous breeds by statal and parastatal organizations. These have resulted in many intermediate populations with no fixed traits and doubtful long-term genetic value. Even where studies have been undertaken they have rarely taken into account the specific production environment and the way this is influenced by climate, feed resources and the level of management. True characterization, other than for morphological parameters, has hardly been attempted. Even in the recent past there has been little awareness of the extent and diversity of the genetic resources in the region, their usefulness and the dangers of their extinction. The fact of and the need for conservation of domestic animal diversity for a range of economic and cultural reasons in a region where the overwhelming mass of the people are poor and traditional in outlook is not generally accepted. The Indian Government is, however, aware of the problem and has had a National Bureau of Animal Genetic Resources/National Institute of Animal Genetics in place since 1984.

It is again possible to establish a preliminary grouping and list of resources which might be considered in need of further attention in South Asia (Fig. 5.7, Table 5.4) The spread of cultivation and increasing human populations are, paradoxically, putting the wild species in danger as domestic stock encroach on their environment and interbreed with them.

Similar maps and tables of priority areas and actions could be set up for the other major tropical regions as could the main reasons for genetic resources being at risk. In West Asia, for example, there is considerable indiscriminate crossing of local with exotic breeds. In this region, however, it is probably malnutrition or even outright starvation that is the main cause of loss: in periods of prolonged and severe drought whole populations may disappear. Some form of national or regional reserve feed bank could help to overcome this problem. Much of the other parts of Asia suffer the same problems as the Indian sub-continent. China, for example, has seen the number of native pig breeds reduced from more than 80 to less than 20 over a period of about 18 years (197896) since economic reforms were introduced. Native Chinese pigslike those of Vietnam and other areas of Southeast Asiaare very prolific but have slow growth rates and are very fat. The present trend is to cross with European types to improve growth rates and increase lean meat content partly to satisfy current consumer demand but tastes may again change.

In South America the situation is somewhat different. Most domestic species were introduced at the time of the European invasion. These breeds and species have, however, adapted to local conditions. 'Criollo' cattle are now to all intents and purposes native breeds and have become adapted, each breed in its own way, to arid or swamp regions and to low and middle altitudes. Some have adapted physiologically and morphologically to local challenges that include short hair with few follicles per unit of skin area, pigmented skin, wrinkles around the eyes, cheeks and neck and thick skin as protection against insect bites. Many of these breeds are now rapidly being reduced in numbers as 'improved' breeds are introduced and so are an obvious target for conservation efforts.

The first priority need not, however, be the imminent threat of extinction. All variation needs to be conserved. Large groups providing many products or supporting many people are candidates for conservation as well as small entities serving apparently limited needs. It must be

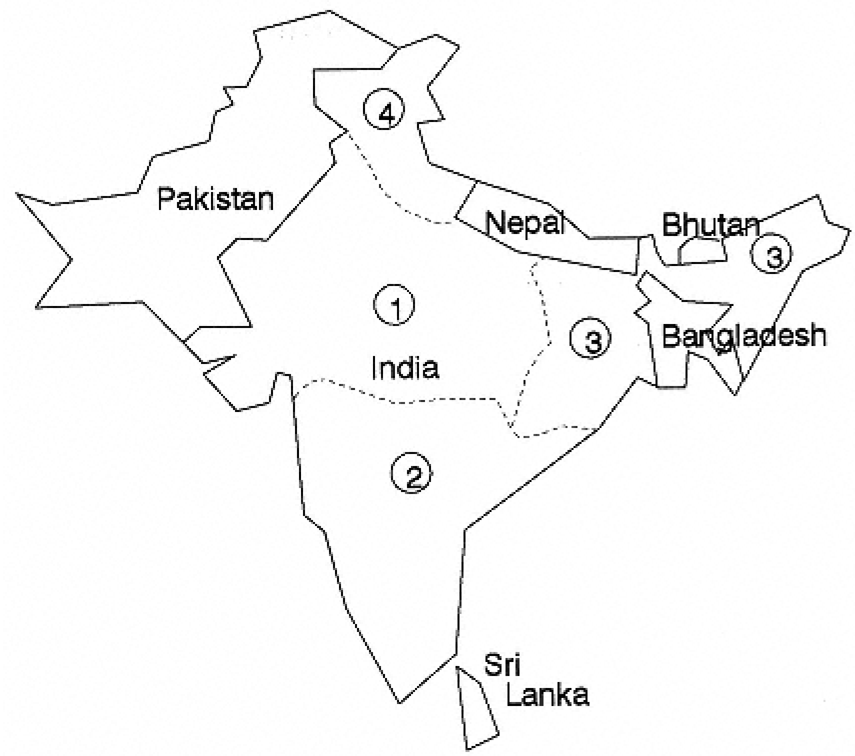


Fig. 5.7
Major centres of diversity of South Asian domestic animal resources. [Indian agroecological regions: 1 = Northwestern arid and semi-arid region (Punjab, Haryana, Rajasthan, plains of Uttar Pradesh, Madhya Pradesh Gujarat); 2 = Peninsular region (Maharashtra, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu); 3 = Eastern region (Bihar, West Bengal, Orissa, Assam, Meghalaya, Arunachal Pradesh, Mizoram, Tripura, Sikkim, Nagaland); 4 = Northern temperate region (Jammu and Kashmir, Himachal Pradesh, hills of Uttar Pradesh).]

stated again that conservation includes current and potential use as well as preservation. A topical example of an animal being bred to fulfil unforeseen conditions (and an indication of the knowledge and capability of traditional owners) relates to the Barka of Eritrea. These people have bred black and white shorthorn cattle for centuries for milk production and docility. Recently, however, docility has been a drawback in the unsettled conditions of war and a less tractable animal suspicious of strangers was needed. Such an animal was produced by outcrossing to the Dohein breed from nearby Sudan, an animal noted for its suspicious nature. The result for the Barka is a less easily controllable animal, demanding more labour for herding and producing less milk than the original purebred. These inconveniences are considered worthwhile, for the present, in reduction of losses due to theft.

In summary, the immediate need is characterization of a range of species and breeds. These should be selected from major agroecological zones and typical livestock production systems. The aim would be to establish sets of data on representative groups. Initially all available information should be gathered, including distribution, numbers, products and current and projected research and development projects. Characterization of animals by modern genetic techniques and the use of biotechnology will then help to establish immediate priorities. Subsequently it will be possible to develop economically and ecologically highly productive animals and breeds adapted to the tropical environment.

Table 5.4 Target areas, species, breeds and production systems for conservation of domestic animal resources in South Asia.

Target area		Species/breeds	Production systems
Bangladesh		Cattle: Broad-faced lyre horned, grey-white short horned zebu group; Buffaloes: Swamp (dairy) types, draught breeds; Goats: Meat types; Poultry	Sedentary
India	Northwestern arid and semi-arid region	Cattle: Broad-faced lyre horned and grey-white short horned zebu groups; Buffaloes: River types: Sheep: Apparel wool types; Goats: Dairy types; Camels; Horses: Kathiawari; Poultry	Mainly sedentary, with some migration especially of sheep and camels
	Peninsular region	Cattle: Broad-faced lyre horned and grey-white short horned zebu groups; Buffaloes: Swamp (dairy) types; Sheep: Meat breeds; Goats: Meat types: Poultry	Overwhelmingly sedentary
	Eastern region	Cattle: Broad-faced lyre horned, grey-white short horned and Indian hill zebu groups; Buffaloes: Swamp (dairy) types; Sheep: Carpet wool breeds; Goats: Meat types; Horses: Bhutia and Manipuri; Poultry; Pigs; Yaks	Sedentary and migratory
	Northern temperate region	Cattle: Short horned (especially Red Sindhi, Sahiwal and Tharpakar) zebu group; Buffaloes: River types; Sheep: Medium wool breeds; Goats: Pashmina types; Horses: Bhutia, Manipuri and Spiti; Poultry	Sedentary
Nepal		Cattle: Indian hill (Nepalese) group; Buffaloes: River and Swamp types; Sheep; Goats; Horses: Spiti; Poultry; Pigs; Yaks	Sedentary and transhumant
Pakistan		Cattle: Short horned (especially Red Sindhi, Sahiwal and Tharpakar) zebu group; Buffaloes: River types; Sheep: Medium wool and meat breeds; Goats: Meat and hair types; Camels; Horses; Poultry	Various
Sri Lanka		Cattle: Sinhala (Indian hill type); Buffaloes: Swamp type	Mainly sedentary

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6
Sustainable Livestock Production Systems

Introduction

In this chapter we attempt to define sustainability; examine the complex interactions of biological, physical and socioeconomic factors that fashion it; consider present production systems, including those in the cool tropical uplands and in subtropical regions into which tropical systems may extend; and finally, examine the dynamics of these systems and probable future trends.

We consider that sustainable animal production requires technically appropriate and economically viable managerial systems that satisfy both fluctuating human needs for high quality foods and animal welfare considerations, whilst maintaining the quality of the environment and the conservation of natural resources. Sustainability is thus a dynamic concept, affected by a number of different and possibly conflicting determinants.

Factors Determining the Sustainability of Systems.

Biological, physical and socioeconomic factors are involved in all production systems and an understanding of the components involved and the dynamics of environmental and socioeconomic change is essential.

Biological Factors

The major biological factors affecting the sustainability of a system are the genetic characteristics of the plant and animal species used, the pests and diseases that affect these species, the special nutritive requirements of the animals and the balance between plant and animal species within the system.

Species Utilized

There are about 250 000 higher plant species and possibly up to 20 000 amphibian, reptilian, bird and mammalian species in the world (Rothschild, 1965). Not all, but possibly a majority, flourish in the varied tropical environments. Tropical peoples only utilize a small fraction of the available species in their agricultural systems. Possibly 100 plant species are used to produce the major part of man's plant food, while less than 20 animal species contribute to most domestic animal production. An important impact of Western agricultural technology in the tropics has been a reduction in the number of varieties and species used for food production. This could spell disaster in the future and it is essential that the diversity of tropical plant and animal species and varieties used for food production should be retained. The problem has been recognized by the Consultative Group on International Agricultural Research (CGIAR) and the conservation of genetic resources, together with the creation of gene banks in the tropics, is generally recognized as essential. Localized cultivars of plants and rare domestic animal breeds may retain genes of major importance for the control of disease or resistance to parasites or for other factors not yet utilized or recognized. The ultimate goal, whichever plant and animal species are used, should be to increase the yield of both plants and animals and thus productivity within the system.

Pests and Diseases

Pests and diseases affect the productivity of both plants and animals in any system. Plant losses can be of the order of 35% of the total crop (Wittwer, 1986), while losses from animal disease and parasites may be even higher. Any intensification of production favours the build-up of pests and diseases in both the plants and the animals within a system. In addition, insects that destroy crops or are major vectors of animal disease are generally more abundant in the tropics than elsewhere. The sustainability of systems thus depends to an important extent on the control of pests and diseases. Good management is essential; including appropriately designed buildings, good hygiene, proper animal stocking rates and adequate veterinary advice and requisites.

Nutrition

Any production system must provide adequate feed for the proper nutrition, throughout the year, of the livestock component. In pastoral systems, in areas that endure a long dry season, provision must be made for the removal of the livestock to a dry-season grazing reserve and/or a supply of supplementary feeds, whilst in humid areas there is every incentive to improve pasture management so that stocking rate is effectively matched with pasture production.

Physical Factors

Soils, water resources and the atmosphere are major physical factors over which man has limited control, whilst the utilization of energy and pollution within the system are factors that man can, but may not, firmly control.

Soils

No other physical factor is more important than the soil. In general, soils throughout the tropics are being degraded, with losses due to erosion exceeding the formation of new soil through weathering (Brown & Wolf, 1984). In traditional shifting cultivation systems, fertility lost during a short cropping cycle of 24 years is replenished during a resting phase that may have to last more than 25 years. With an increase in population the resting phase in shifting cultivation systems has tended to be reduced to such an extent that soil fertility is no longer replenished, there is less feed for ruminant livestock and less wood to use as fuel. Under these circumstances traditional shifting cultivation systems become unsustainable.

Water

The rainfall in any region usually dictates what type of agricultural system is sustainable. The exception is the irrigated area that may be sited in a low rainfall region but may be fed by river water flowing from a high rainfall region. There has been a dramatic increase in the use of water for irrigation purposes during the twentieth century. In drier areas the availability of surface water dictates the form of the livestock production system. In deserts only camel husbandry is sustainable, while in regions with a long dry season cattle and cattle/sheep/goat production systems may be sustainable if surface water is available throughout the year and there are adequate dry season feeding areas.

The Atmosphere

The effect of gases that human activities release into the atmosphere may be either harmful or beneficial. Combustion of fossil fuel and the smelting of metallic ores release quantities of sulphur and nitrogen oxides into the atmosphere. These are returned to the soil in the form of compounds dissolved in acid rain that may be harmful to both terrestrial and aquatic life. On the other hand, acid rain may return sulphur to sulphur-deficient soils, improving both plant and livestock productivity. The burning of wood and other fossil fuels releases large quantities of carbon dioxide. The direct effect on plants and

indirectly on livestock is beneficial as higher concentrations of carbon dioxide in the atmosphere improve plant photosynthesis, water utilization efficiency and hence productivity. The long-term indirect effects, however, may create many difficulties, leading to the 'greenhouse effect' with a future 25°C increase in the mean temperature at temperate latitudes, possibly creating a rise in sea levels and a change in rainfall distribution (Oram, 1987). Ruminant livestock and wet rice culture produce significant quantities of methane that can intensify the 'greenhouse effect'.

Utilization of Energy.

If the energy efficiency (EE) of a system is expressed by the equation:

$$EE = \frac{\text{energy harvested in the form of food}}{\text{energy expended in food production}}$$

then the EE of the shifting cultivation and subsistence mixed farming systems would be <1.0 and that of a high yielding modern arable crop system would be several times >1.0. If the crops produced are fed to ruminant livestock the EE would dramatically decline, particularly if the manure produced by the livestock is not utilized. If the crops are fed to pigs or poultry the EE would be higher than when fed to ruminant livestock. Thus, the fertility of the soil can be maintained and production intensified if nonrenewable sources of energy are introduced into the system. At a time when fossil fuels are abundant it is rational to maintain fertility with high food output at the expense of introduced energy in the form of fossil fuel. This is, however, for all mankind a medium-term policy and ultimately other actions will be required.

Chemical Pollutants

It is possible for the sustainability of any system to be threatened by a chemical pollutant. For example, DDT known to be a cost-effective insecticide, has been found in practice to be toxic to some components of life systems. Also fertilizers applied in the wrong quantity and at the wrong time can be harmful, whilst a high salt content in the water can quickly wreck an irrigation system.

Socioeconomic Factors

In the tropical world, where populations are increasing rapidly, traditions are challenged and industrialization is occurring, the attainment of sustainable agriculture requires major socioeconomic changes. These could include changes in economic policy, tenure, rural infrastructure, credit and institutional support.

Economic Policy

In many developing tropical countries, particularly in Africa, an urban elite has pursued biased development strategies, creating an over-valued currency and has also encouraged the transfer of capital from agricultural to industrial projects. Such strategies have been one reason for the failure of these countries to develop sustainable agricultural systems.

Tenure

There is considerable confusion with regard to tenure in many tropical countries, particularly those with a large pastoral sector. In some, traditional communal, tenurial rights are impeding necessary changes, whilst in others tenants are inadequately protected by law. Some of these problems in African rangelands are discussed in detail by Lane & Moorehead (1995). Sustainable systems in pastoral regions must be supported by fair and adequate tenurial and/or ownership rights.

Rural Infrastructure

Lack of infrastructure such as roads, communication systems and markets is a constraint on any agricultural system and probably on the adoption of new technology.

Credit

The development of sustainable systems is often blocked or deferred on account of the limited number of financial institutions serving rural areas that are able to accept savings and provide loans required for the purchase of essential inputs.

Institutional Support

The development of sustainable systems requires countries to prioritize research, extension and education. Progress in most countries is slow. It is generally accepted (Oram, 1987) that research funding should range between 0.5 and 2.0% of the agricultural gross domestic product (GDP) but few if any tropical countries even spend the minimum amount. National agricultural research systems, particularly in Africa, are usually inadequately funded, lack continuity in their programmes and lack a critical mass of researchers. The establishment of the International Service for National Agricultural Research (ISNAR) by the CGIAR has undoubtedly, during the last decades of the twentieth century, assisted the gradual improvement of national research systems. There is, however, not only weakness in national research but also in the extension services and in the training of personnel to staff the research and extension services; retarding the development of sustainable systems.

Traditional and Developing Production Systems

There have been many proposals as to how production systems can be classified. Some are listed in Chapter 7 in the discussion on cattle production systems. As Wilson (1995) has stressed, there are a number of alternative methods. These include:

- whether traditional or 'modern' (subsistence or commercial);
- whether extensive or intensive (in relation to land-use intensity);
- according to geographical location;
- according to climatic zone;
- in relation to the type of crop and/or animal produced; and
- according to production objective (milk, meat, draught, manure).

Any classification must be simple and based on universally recognized criteria. We propose a classification based on two major criteria; these are:

(1) whether the system is extensive, semi-intensive or intensive in relation to land use; and

(2) whether it is a subsistence, semi-subsistence/ semi-commercial, or a commercial system.

The proposed classification is as follows:

I Extensive systems

Subsistence or semi-subsistence

- Traditional pastoralism
- Shifting cultivation (slash/burn)

Commercial

- Ranching
- Game cropping

II Semi-intensive systems

Semi-subsistence/semi-commercial

- Sedentary crop agriculture with livestock. Includes mixed farming systems in the highlands and lowlands and agro-pastoral systems in semi-arid areas

Commercial

- Crop irrigation: intensive crops with extensive livestock

III Intensive systems

Subsistence or semi-subsistence

- Rural landless and urban livestock

    conventional livestock

    microlivestock

- Integrated production

    systems integrating livestock with arable and tree crops

    systems integrating livestock with fish, aquatic plants and crops

    ley farming

- Modern sector livestock production

dairying and beef production

pigs

poultry

Any classification system is based on some arbitrary decisions and our proposal is no exception. The demarcation lines between extensive and intensive systems are always changing as is the definition of subsistence or commercial in relation to specific systems. Nevertheless, we consider the above to be the most suitable system proposed to date.

Extensive Systems.

Traditional pastoralism, ranching and game cropping are systems that have been adopted to exploit the extensive arid and semi-arid regions of the tropical world. The shifting cultivation system, developed in the past in humid bush or forested regions, has been used to exploit regions with a very limited population and more or less unlimited land. In many tropical regions these conditions no longer exist.

Traditional Pastoralism

Today, in the tropics and subtropics, the practice of traditional pastoralism is almost entirely confined to certain regions in West, East and Northeast Africa, Western Asia and the northwest of the Indian sub-continent. Within, and on the fringes of the deserts of Africa, Western Asia and India, camels have been the main type of livestock used in the production system; for transport and milk and meat production. In Western Asia, particularly in the oil-rich countries, the use of the camel for transport purposes has declined, as has the traditional pastoralist system. There is, however, evidence that in some semi-arid regions of East and Northeast Africa camels have to a limited extent, replaced cattle as the major livestock component in the local production system.

Systems in which camels are used are, however, limited in number and in extent. Cattle are the major livestock component in almost all traditional pastoralist systems (Fig. 6.1). These dif-

Fig. 6.1
Traditional pastoralism in Sudan. Baggara livestock feeding on tree forage cut for them during a drought period.

fer, but there is a continuum (see Chapter 7) between those systems in which the livestock owners practise little or no cropping, through forms of partial nomadism and transhumance to systems in which sedentary cultivation is the norm but some members of the family move with the family livestock within a limited grazing area for specific periods of the year. In almost all these systems it is usual for the pastoralists to own and herd some sheep and/or goats. The latter may be run with the cattle but are more often herded separately, often by women and/or children.

There are also traditional transhumant pastoral systems, mainly in subtropical regions, in which the major livestock components are sheep and goats, though the family may own a limited number of cattle and/or camels. These are usually what might be termed 'vertical transhumant systems' as the livestock are trekked into upland regions for that part of the year in which feed is available and return to the lowlands for the remainder of the year. These systems are mainly located in Western Asia, particularly in Iraq and Iran, but there are a small number in Africa, some on the uplands in the southern and southeastern fringes of the Sahara desert, whilst in semi-arid, subtropical regions of South Africa, Botswana and Namibia there are specific Karakul sheep pelt production systems.

The donkey is employed to a limited extent for transport in some extensive livestock systems, particularly the more sedentary type. Camels and cattle are used for both riding and transport in specific systems.

Productivity

Productivity of the cattle-based pastoral systems is discussed in detail in Chapter 7. According to the degree of nomadism traditional pastoral systems produce milk, meat and sometimes blood from domestic animals and varying quantities of food from crops. Investigations by Behnke & Scoones (1993) and Scoones (1995) suggest that traditional pastoralism is more productive than ranching on a production per unit area basis but far less productive per individual employed. It is undoubtedly a more responsive system, particularly in semi-arid regions, if it is conducted within a sufficiently large area, as in ranching systems a specific number of livestock are confined within a specific area, irrespective of climatic, and hence pasture and forage, conditions.

Shifting Cultivation

Shifting cultivation or 'swidden' as it is known in Asia, may once have been an almost universal agricultural system in the humid and moist forest areas of the tropics and subtropics. The continued existence of the system, however, depends upon the ability of a small population to exploit extensive areas of forest. The situation is changing very rapidly as large swathes of tropical forest are denuded by logging companies and as human populations expand. Under these circumstances it must be expected that the system will be replaced by more productive but probably more labour intensive systems.

The principal forested areas where shifting cultivation is still practised are:

• *Asia and Oceania*. Primarily in the uplands of northeast India, Bangladesh, Myanmar (Burma), Thailand, Cambodia, Laos, Vietnam and southern China, in some of the islands of Indonesia and the Philippines, in New Guinea and in some of the larger Pacific islands.

• *Africa*. In the forest areas of West Africa: primarily in the Côte d'Ivoire and Cameroon.

• *Americas*. In the indigenous Indian regions of Mexico and Central America, particularly in Guatemala, on the Pacific coast of Colombia and in the Amazon basin in South America.

In shifting cultivation areas the livestock utilized have been mainly pigs and poultry, sometimes together with a few goats and sheep and occasionally cattle and/or buffaloes. There are, however, two regions in which cattle in number have been associated with the systemthe trypanotolerant N'Dama and West African Shorthorn breeds in West Africa and criollo cattle in the Amazon Basin of South America.

As human populations have increased and the availability of land per family has decreased the shifting cultivation system has evolved on a different time scale in different regions in the general manner shown in Fig. 6.2.

Shifting cultivation with a forest fallow system of 25 years or longer can be an inherently stable system but as forest land area availability decreases and the fallow period shortens, stability decreases, primarily due to a fall in fertility and increased weed invasion. Ultimately, as the fallow period shortens further a sedentary system has to be adopted and the fertility of the system has to be maintained by the introduction of as many livestock as possible to produce manure, the growing of bush or other legumes during the

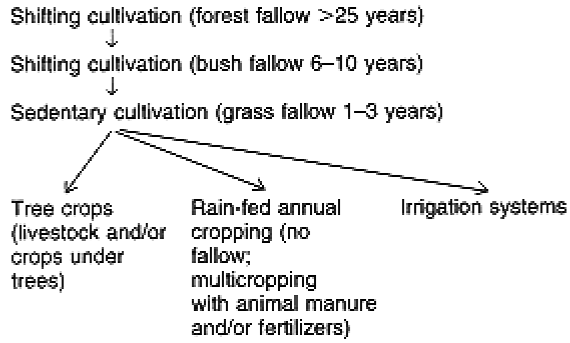

Fig. 6.2
General pattern of the evolution of shifting cultivation to modern production systems.

fallow period, or the use of artificial fertilizers. Preferably a combination of the first two, or all three, methods.

The shifting cultivation systems in which cattle are integrated are discussed in Chapter 7 and others that have evolved as sedentary systems replacing shifting cultivation are discussed later in this chapter. A shifting cultivation system in northeast and southern Brazil, is, however, of special interest. Landowners wishing to clear rainforest for cattle production lease land to shifting cultivators who cut and burn the vegetation, crop for 1 or 2 years and then move to a new area of the forest to repeat the process. The landowners pasture their cattle on the cleared area.

Ranching

Ranching is an alternate system to various forms of pastoralism. There are, however, two fundamental differences. In ranching, livestock are raised to provide a cash income whilst in pastoralism their primary role is to provide food for the family. The other difference is that in ranching the stocking rate has to be adjusted to the carrying capacity of a limited pasture area whilst in pastoralism adjustments to carrying capacity are made by moving the livestock to new pastures on the communal grazings. As stated previously, pastoralist systems are efficient in production per unit area of land, though subject to overgrazing, whilst ranching is more efficient in production per person employed and within the system it is easier to control overgrazing.

Ranches stocked with cattle are the predominant livestock systems in the American tropics and subtropics. To some extent this is due to an historical accident. There were no domestic cattle or buffaloes in the Americas when the first discoveries were made by Europeans in the fifteenth century. The first introductions of cattle initiated a development that was ultimately to lead to an extraordinary expansion in cattle numbers in mainland North and South America (Payne & Hodges, 1997).

Cattle ranching systems are at present predominant in some of the drier tropical and subtropical pastoral regions of the southern United States, Mexico, Central and South America and in the last they are also established in more humid areas. In tropical South America and, in particular, in the Amazon basin, large areas of rainforest have and are being felled to provide pasture for cattle. Not all ranching systems are primarily beef producers. Throughout Central and South America there are a limited number of ranch or extensive milk producers. Cattle ranching has ultimately flourished in tropical America despite the fact that the first introductions of cattle came from Europe. The introduced cattle slowly acclimatized in the drier tropical and subtropical regions and became known as *criollo* cattle in Spanish speaking countries and *crioulo* in Portugese. First in Brazil and later in Mexico and in the southern United States tropical cattle breeds were introduced and by the twentieth century new crossbred (tropical × criollo or temperate-type) breeds had been produced that were acclimatized to tropical climates (Payne & Hodges, 1997). During the twentieth century individuals of these new breeds have been exported to tropical regions in Africa, Asia and Oceania. Further details of the utilization of cattle in American ranching systems are provided in Chapter 7.

Buffaloes, domesticated for centuries in Asia and southeastern Europe, were first exported to the region of the lower Amazon in Brazil about a century ago (National Research Council, 1981). They are generally maintained under what may be described as extensive or ranching conditions and have multiplied very rapidly so that they now number more than 1.5 million (see later in Table 8.1). Since their successful establishment in the lower Amazon basin buffaloes have been introduced into other Central and South American countries, including Venezuela where there were 25 000 head by 1994 (see Table 8.1). There are also a small number of buffaloes herded under extensive conditions in northern Australia, New Guinea and Sumatra, and buffaloes have recently been introduced into the southern United States.

The success of crossbred and zebu cattle in the American tropics led to their introduction into

Australia. As in the Americas there had been no cattle in Australia before European colonization. Also, as in the Americas, the colonizers introduced their own European-type cattle in large number, though a small number of zebu cattle were introduced as ships sailing from Europe to Australia called at Asian ports and frequently loaded local zebu cattle, usually but not always to provide meat during the voyage. More or less the same problems with European-type cattle were encountered in subtropical and tropical Australia as were encountered in the Americas. Australians were, however, able to benefit from American experience and although there was initial hesitation, crossbred and zebu cattle were introduced in number into Australia in the twentieth century. These cattle were also introduced into New Guinea, Fiji and other Pacific islands where small ranching sectors existed.

The situation has been somewhat different in Africa and Asia, though in specific countries ranches were established during the nineteenth century or earlier. In Kenya a limited number were established, principally in the Rift Valley, on the Athi plains and on the Laikipia plateau. Although the first Kenyan ranches were stocked with imported European-type cattle, on account of high mortality these were quite rapidly replaced by the indigenous Boran. Indigenous breeds have also been favoured on the few Tanzanian ranches (Wilson, 1995). In Zimbabwe and Zambia the majority of ranches were originally stocked with introduced European-type cattle, but the use of indigenous breeds such as the Mashona is increasing. In Southern Africa ranching systems have been established in the drier regions for considerably longer than elsewhere in Africa. They include cattle ranches using indigenous, crossbred and introduced European-type cattle, and particularly in southern Botswana and Namibia, large- and medium-sized sheep ranches producing high quality wool or Karakul pelts (Wilson, 1995). During the twentieth century cattle ranches have been established elsewhere in Africa, particularly in West and Central Africa. Some were sponsored and funded by international agencies that had concluded that traditional pastoralism was outdated and must be superseded by some form of ranching. Experience has proved otherwise.

Few ranches have been established in tropical Asian countries. The Philippines has been an exception, where, on account of traditional Spanish and American cultural attitudes and (at the beginning of the twentieth century) a relatively small population and large areas of underutilized land, cattle ranching became established in a few regions. A very small number of cattle ranches have also been established in Malaysia and Indonesia.

Game Cropping

Man, when able, has always hunted to provide meat for his family and/or for the excitement of the chase, but it is only in the twentieth century that efforts have been made to organize the commercial harvesting of meat from wild game. For game cropping to develop as a profitable economic activity it must possess some advantages over conventional domestic livestock production and other possible systems. It is likely to possess economic advantage in arid and semi-arid regions where most domestic livestock production is marginal, where there is a high game biomass comprising fertile game species that produce high quality meat or other marketable products and where markets are readily available for those products. The advantages and disadvantages of the system are discussed in some detail in Chapter 16, as are some of the practicalities of producing meat within the system in Chapter 19.

Within the tropics and subtropics, possibilities for the development of game cropping at the present time are most promising in East, Central and Southern Africa. Indeed, there are at least some 8000 ranches in South Africa where some form of game cropping is already practised, together with a considerable number in Central Africa and a few in East Africa. Outside Africa there are kangaroo cropping schemes in Australia, minor schemes in Asia for the cropping of antelopes and in South America for the cropping of capybara (*Hydrochoerus hydrochaeris*) in the *llanos* of Venezuela and Colombia, tapir (*Tapir terrestis*) in the Amazon basin and vicuña (*Lama vicugna*) in Peru.

Semi-Intensive Systems

These are rain-fed systems in which crop agriculture is integrated to a greater or lesser extent with livestock production. Geographically they are located in different regions of the tropics and subtropics having evolved from some form of pastoralism in the drier areas or from shifting cultivation in the more humid areas, but they all have certain features in common. In general the holdings are small, the economy is a mixture of semi-subsistence and cash, cattle and/or buffaloes are primarily used for work purposes, though milk production is very important in certain countries and of growing importance almost everywhere, whilst sheep and/or goats and poultry are usually husbanded in small numbers everywhere and pigs are numerous in specific regions. All can be classified under a general title as 'sedentary crop agriculture with livestock'.

Sedentary Crop Agriculture with Livestock

Steinfeld and Mäki-Hokkonen (1995) identified three subsystems on a climatic basis: those in the tropical highlands, those in the humid and sub-humid tropics and those in the semi-arid tropics and subtropics. Wilson (1995) has evaluated specific systems within the three subsystems.

The most important in terms of the number of population involved is the semi-arid tropics and subtropics rain-fed system. This is of importance in Western Asia, part of the Indian subcontinent, northeast Thailand and other regions of Southeast Asia, North Africa and the Sahel and to a lesser extent in some smaller regions in Central and South America. Goats and sheep are of particular importance in Western Asia and North Africa while cattle and/or buffaloes are of major importance in South and Southeast Asia. The development of dairying in this and the humid and sub-humid areas of the region has been, and continues to be, of great importance, as detailed in Chapter 7.

The major problem in the system is the relatively low output of crops and forage due to limited rainfall with a resulting short growing season. In addition, on account of past deforestation there are fuelwood shortages and animal manure that should be used as a fertilizer is more often used as a fuel. There are obvious limits to intensification, low and variable responses to capital injection and the introduction of new technology and a need to curb the growth of the human population.

The humid and sub-humid tropical and subtropical system is very heterogeneous and is found in various forms throughout the wetter tropics. It is important wherever shifting cultivation has been replaced by a more permanent system. In Asia some form is established in the more humid regions of South Asia, Sri Lanka, upland areas of mainland Southeast Asia and some regions of the Philippines and Indonesia, also in New Guinea and in some of the larger Pacific islands. There are different forms of the system in West (Fig. 6.3) and Central African countries and in some of the more humid regions of East and Southern Africa. The system has also become established throughout the more humid regions of Central and South America and some larger islands in the Caribbean.

The major types of livestock husbanded in

Fig. 6.3

Sedentary crop agriculture with livestock in
Wadara, Nigeria. Livestock grazing on crop stubble.

these heterogeneous systems are cattle and/or buffaloes and poultry with sometimes a few sheep and goats. Pigs are of some importance in the systems in Southeast Asia, West Africa and Central and South America. There are special problems for livestock in the hot humid tropics (see Chapter 1). These are not only physiological, such as the ability of livestock to adapt to the very harsh climate, but are also concerned with their protection from the many parasites that thrive in the humid tropics. It is also necessary to evolve different and more efficient husbandry and feeding methods as although forage and pastures may be productive, they age rapidly, are low in protein and high in fibre content and are generally of low nutritive value (see Chapters 1 and 3). An additional constraint within these systems in many areas of Africa is the high incidence of trypanosomosis.

The tropical highlands system is somewhat similar to the dominant system found in the temperate regions of North America, Europe and northeast Asia. It exists in a few isolated montane areas in Asia but is found primarily in the highlands of eastern Africa, i.e. in Ethiopia, Kenya, Tanzania, Uganda, Burundi, Rwanda and a region of eastern Democratic Republic of Congo (formerly Zaire), and in those of Central and South America. Temperate-type breeds of cattle, sheep and goats may be utilized in this system whilst in South America there is the alternative of using camelids.

It is a system in which low environmental temperatures may limit the production of forage and pasture and provide the need for some form of shelter for most types of livestock.

Crop Irrigation:
Intensive Cropping with Extensive Livestock

In 1965 the major part of irrigated land in the tropics (84%) was located in Asia, primarily in South and Southeast Asia. Even in 1995, although the total area of irrigated land in the tropics had almost doubled, with large increases in Africa, Central and South America, 79% of the total area was still to be found in Asia (FAO, 1966, 1995). The major crop on irrigated land in tropical Asia was, and still is, rice (Fig. 6.4). According to the type of soil, total amount and seasonality of rainfall and local custom, rice may be a multi-crop, or a single crop, followed by other crops such as green legumes or vegetable crops. Whatever the subsystem the rice stubbles are usually grazed for a period after harvest by livestock; primarily buffaloes, cattle, goats and poultry in Asia and cattle, goats and sheep in West Africa, Central and South America.

In the past, stubble grazing and crop byproducts such as straw and rice bran provided a significant proportion of the annual diet of farmers' livestock. Indeed, in specific regions of Asia, a migrant duck farming system (see Chapter 15) was founded on the seasonal availability of rice stubbles in which flocks of ducks could scavenge for fallen whole rice grains, snails, insects, frogs and green weed vegetable materials.

Multiple rice cropping and new agricultural practices have reduced the viability of some systems for integration with livestock. New rice varieties are short-strawed, providing less straw for livestock and their straws are also often lower in feeding value than the varieties that they replaced. Increased use of herbicides has reduced the availability of 'weed forage' in the stubbles and increased pesticide use has multiplied the risk of livestock poisoning and decreased the

Fig. 6.4

Intensive cropping with livestock in Madura, Indonesia. Harrowing a rice field using Madura cattle.

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availability of insects, frogs and small fish in the fields. In some regions increased mechanization of the rice crop has removed feed byproducts from the immediate vicinity of the rice farms.

Intensive Systems.

Not all intensive systems are fully commercial operations. There are landless families, both within and outside urban areas who husband livestock under very intensive conditions and sell some part of what is produced, whilst there is an even larger urban population who husband livestock under back-yard conditions, often but not always microlivestock, in order to provide food for their families.

Rural Landless and Urban Livestock

Many of the rural landless and poor urban population of tropical cities are livestock producers. They may be divided into two groups: those who raise conventional livestock under unconventional conditions and those who husband microlivestock. The majority are primarily subsistence producers but they may sell surplus products. A minority of them produce for the market.

Conventional Livestock

Families who do not own any land apart from that on which their house is built may own and husband conventional livestock: non-ruminant poultry and pigs, ruminant cattle, sheep and goats, together with horses and donkeys and even camels.

Poultry can be kept in the house yard and allowed to scavenge, being fed whatever household scraps are available. The larger the household, often the larger the number of poultry kept. The system varies to some extent from region to region. In West Africa, according to Wilson (1995) producers often own a combination of poultry: fowls, Guinea fowls, Muscovy ducks and pigeons. In Southeast Asia, however, the landless producer may be an itinerant, husbanding only one species, ducks, from rice field to rice field.

In West Africa and in Southeast Asia the pigs of the landless are allowed to scavenge on rubbish heaps and middens and are usually fed small quantities of by-product feeds such as bran.

Cattle, buffaloes, sheep and goats owned by landless families graze roadside, railway and drainage ditch verges and any other waste land available. In the drier tropics a limited number of urban goats rove the streets and appear to thrive on organic rubbish. In South Asia, where there has been a tradition of landless itinerants owning one or more milking cows or buffaloes and selling milk from door to door, that is taken directly from the animals, the development of milk collection centres that replace the itinerants has been very successful. Some details of the growth of these centres in India are provided in Chapter 7. Wilson (1995) provides a case study of peri-urban milk production in Mauritania where the major part of urban milk production is from camels, though there is also production from cattle and goats.

Transport animals are often owned by landless families and housed in their yard, but if regularly used for transport purposes the owners can usually afford to purchase fodder and concentrates. If only used occasionally, as are many donkeys, they may have to scavenge to keep alive.

Microlivestock

Definitions of microlivestock differ. The National Research Council (1991) suggested that there are two types. One group consists of livestock that are small versions of conventional livestock species, whilst the second group comprises livestock species that are inherently small. Poultry were included in the definition of microlivestock but we consider poultry separately in Chapter 15. Some of the livestock that were classified as inherently small are listed and described in Chapter 17. They include rabbits, vizcacha, Guinea pigs, cane rats, grass cutters, capybara, mouse deer, muntjac, iguana and snails. There exist, of course, many other minor

species that could be listed as microlivestock, at least 150 according to Wilson (1995).

The importance of these inherently small species is that they:

- Are in general highly adaptable and occupy environmental and economic niches not easily taken up by larger livestock.
- Are relatively cheap to purchase, house if necessary, feed and manage.
- Demonstrate in general short life cycles and high reproductive rates with a rapid return on investment.
- Are usually efficient convertors of food, producing carcases with a high lean and low fat content.
- Produce valuable by-products such as skin, pelts and fur.
- Their development as domestic or semi-domesticated livestock will maintain and possibly enhance biodiversity.

Constraints on microlivestock husbandry are that they:

- Are relatively inefficient converters of feed to meat as their basic metabolic demands are high compared with that of larger livestock.
- May be reservoirs for disease and/or parasites.
- May require intensive labour in their husbandry.
- Are an easy prey for predators.
- Could attract legislative restrictions as to where and how they are housed and where their products are marketed.

The majority of producers of microlivestock are likely to be landless families in rural areas and poor families living in the peri-urban areas of the large tropical cities. There will, however, be individuals and families in all sedentary systems, but particularly in the sedentary 'crop agriculture with livestock system' who will husband some type of microlivestock. In particular, women and children manage microlivestock. In general, the participants listed will be semi-subsistence producers, raising microlivestock in order to improve the diet of their families, but also selling some produce to their neighbours or possibly to small co-operatives or local shops. There are also a limited number of small- to medium-sized commercial producers, particularly of rabbits, guinea pigs and snails, who sell through markets. Wilson (1995) reported that small specialized markets for guinea pigs have developed in the larger Andean cities and it is estimated that there are about 20 million guinea pigs in Peru producing about 16 000 mt/a of meat, equivalent to about 80% of the mutton output in the same region.

Integrated Production

These are systems in which two or more components, one of which is livestock, interact in such a manner as to increase the overall production of the whole system. They are therefore intensive systems, but at their present stage of development they are not necessarily entirely commercial in operation. They do, however, possess commercial possibilities.

Two major systems are considered. Variations exist and attempts have been made to combine them into one overall system (Preston, 1990). The two systems are:

- The integration of livestock with arable and tree crops.
- The integration of livestock with pond fish and crops.

Systems Integrating Livestock with Arable and Tree Crops

This idea is not new. Livestock have scavenged in the fields after crops have been harvested and trees and bushes have been browsed by domestic livestock for centuries. What is new is that planned integration can be used to intensify production.

Agroforestry is the collective name for the land utilization system that combines the use of crops, trees and livestock, in varying degrees of spatial and temporal sequence. The major, but not all, ways in which livestock, trees and crops may be integrated are shown in Fig. 6.5. Nair

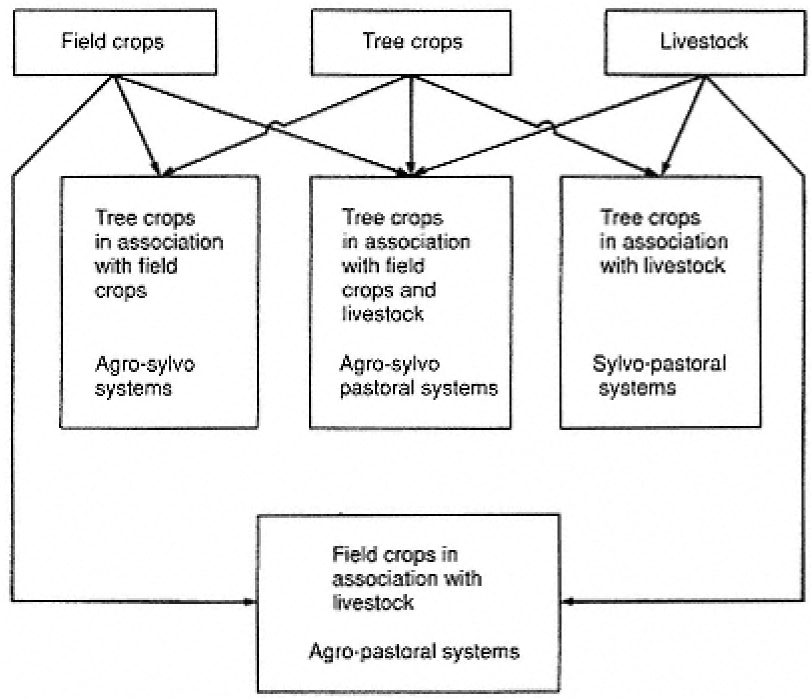

Fig. 6.5
Diagrammatic representation of the possible associations of field and tree crop production with livestock production.
(Source: Payne, 1985.)

(1987) has also listed some other associations such as:

• The linear planting of trees and hedges along roads and around field boundaries, that can provide timber and shade, shelter and browse for livestock.

• The *taungya* system or sequential cropping of crops and trees providing timber, crops and crop by-products and cut forage for livestock.

Agro-Sylvo Systems

Some details of these systems in which cattle are the major livestock component are provided in Chapter 7. One of the systems, known as alley farming, alley cropping, or hedgerow intercropping, has been developed experimentally in West Africa and there are now large-scale trials in several tropical regions (Kang, 1993).

The basic concept is that crops are grown on approximately 4 m wide arable land strips between parallel hedges, the hedgerows being cut at appropriate intervals to provide either mulch as fertilizer for the soils in the strip or feed for livestock. Generally leguminous trees and shrubs are grown in hedgerows that are orientated and cut to a height that minimizes crop shading. Livestock could be grazed on the crop stubbles or on a planted forage crop and browsed on the hedgerow. A system investigated in Fiji and in Hawaii in the 1950s, used the legume *Leucaena leucocephala* as the hedgerow plant. This system was abandoned in the Pacific countries as managerially too complex. In current investigations of 'alley farming' hedgerow forage used as livestock feed is normally cut and carried to the livestock.

According to Kang (1993) the best response to the 'alley farming' system is on clay soils in the humid and sub-humid tropics where crop production can be sustained with low chemical fertilizer inputs. Carter (1995) stated that alley farming is unlikely to become a major system as there are a number of constraints, including its unsuitability for the types of crop and crop combinations grown by many farmers and its high and inflexible labour requirements. The system is also inappropriate for farmers who do not

possess secure long-term tenancies and for farms on acid soils where there is still a need to identify suitable nitrogen-fixing leguminous species.

Agropastoral Systems

There are a number of these systems in which livestock are fed on the by-products of crops, either in the field after the crops have been harvested or in feedlots to which the by-product feeds are transported. The simplest agropastoral system is one in which ruminant livestock feed on crop stubbles after the crop has been harvested. This is usually operating as a semi-intensive system but it is one in which intensification can easily be introduced. As detailed in Chapter 7 sugar cane, pineapple and sisal are crops with which cattle production can be integrated. Sugar cane in particular provides three feed by-products for livestock: green tops, molasses and bagasse.

Sylvo-Pastoral Systems

Forests, particularly open dryland forests, have been traditional grazing areas but the integration of livestock with commercially grown tree crops is a relatively new concept. Payne (1985) reviewed the possibilities and in particular those in cattle/coconut (Fig. 6.6), cattle/oil palm, cattle/rubber and cattle/fruit crop systems. The integration of livestock with timber trees is also a system under investigation and development, particularly in the American tropics and in Oceania.

Systems Integrating Livestock with Fish, Aquatic Plants and Crops.

An overall, theoretical concept of this form of integrated production is shown in Fig. 6.7. Crops could provide feed for livestock managed adjacent to or above the fish pond and for the fish maintained in the pond. Alternatively, feeds for livestock and fish could be purchased. Manures produced by the livestock would be channelled into the pond where their nutrients would improve the production of microorganisms and small pond plants on which the fish feed. The

Fig. 6.6
Integrated production in Sarawak, Malaysia. Cattle managed under coconuts on the perimeter of a village.

supply of nutrients could be improved by adding fertilizer to the manure. Nutrients added to the pond water could be used by surface vegetation, if any were allowed to grow. Surface vegetation could be fed to livestock and any surplus pond water used for irrigation.

At the present time, according to Edwards *et al*. (1996) about 90% of the world's aquaculture industry is located in Asia and of the Asian industry about 9% is in South Asia, 13% in Southeast Asia and the remainder in Eastern Asia (mainly China). At present, only a very small percentage of fishpond enterprises in Asia are integrated with livestock and/or crops and of those that are integrated the majority are probably of the duck/fish type. Nevertheless, during the second half of the twentieth century there has been research conducted throughout Southeast Asia and elsewhere into systems in which livestock and/or crops are integrated with pond fish production.

In Southeast Asia the major fish cultured have been various types of carp and tilapia. Ruminant livestock, such as buffaloes, cattle and goats have been used to provide manure but in general ruminant manure is inferior in nutrient content to the manure of pigs, ducks and other poultry. In

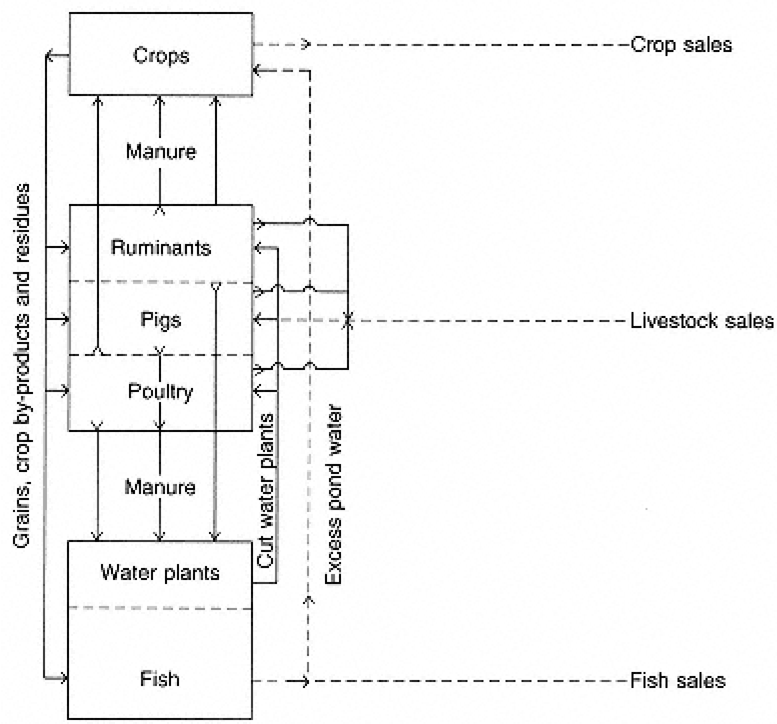

Fig. 6.7
Diagrammatic representation of an integrated (livestock:aquatic plant:fish:crops) system.

some South and Southeast Asian societies, however, there are cultural and aesthetic objections to the use of pig manure.

At present the duck/fish system has probably been more thoroughly investigated than any other. Ducks can be housed on the pond bank or preferably over the pond and in best practice are allowed to use about one quarter of the total pond area, in which they can scavenge for insect larvae, snails, aquatic weeds, etc. Under these circumstances the digestive protein content of their introduced feed can be reduced from about 1618 to 1314%. According to Edwards (1986) about 3035% of the nutrients in their food will be voided in their excreta while about 10% of their food is spilt whilst feeding and will end up in the pond. Nutrients from the excreta and the spilt duck feed can replace about 30% of the total feed requirements of the fish. Investigating smallholder systems, Edwards (1983) has shown that the manure from 27 ducks will provide sufficient nutrients to produce 175 kg of fish per 200 m2 water per year.

Ley Farming

Ley farming is a form of integrated production in which pastures are rotated with crops in a 3- to 5-year cycle. Research in East Africa in the mid-twentieth century showed that it was an economic and viable system in the Kenyan highlands for the production of milk, meat and wool using temperate-type crops and livestock under montane tropical conditions. The difficulties are that the system requires relatively large farms, a considerable degree of mechanization and a high degree of managerial skill; preconditions that do not exist throughout most of the montane tropical world. Some details of the system in montane East and Central Africa and elsewhere in the tropical world are provided in Chapter 7.

Modern Sector Livestock Production

This sector includes the production of milk from dairy cattle and buffaloes, of meat from beef

cattle, pigs and poultry and of eggs from poultry. The extent of modern sector livestock production varies from country to country in the tropics, but it is increasing at the expense of more traditional systems in virtually all countries.

Some form of modern, specialized, dairying industry has developed in most tropical countries. In some, it may only be a limited number of government-funded experimental dairy farms, but in others it has become a rapidly expanding co-operative or private industry. Milk production has more than doubled in tropical Africa, Central America, South America and Oceania and increased substantially in Asia during the period 1965 to 1995 (FAO, 1966, 1995). In part this tropics-wide increase in milk production is due to an increase in modern sector dairying. Husbandry in the latter is detailed in Chapter 7.

Modern sector pig meat production in the tropics is at present concentrated in non-Muslim Southeast Asia, Central and South America, East, Central and Southern Africa and Oceania. According to FAO statistics there has been an increase of more than 300% in the production of pig meat in the tropics between 1965 and 1995 (FAO, 1966, 1995). Even if some part of this large increase in production is discounted, due to possible incomplete reporting in 1966, a substantial real increase in production has occurred due in large part to modern section production (details of which are provided in Chapter 14).

A modern sector poultry industry has been established virtually everywhere in the tropics (Daghir, 1995). Details of small-scale modern sector broiler and egg production units and traditional poultry husbandry are provided in Chapter 15.

Possible Future Trends in Production Systems

Traditional Pastoralism

There is no doubt that traditional pastoralism is beset with problemspolitical, social and economicand that in general the system is in decline. The reasons are manifold and in very general terms they are that:

- Governments do not in general understand pastoralist values or their contribution to society and often would prefer to pursue sedentarization policies.

- Pastoralists are generally conservative in their attitude to new ideas and change and are often not very co-operative with governments.

- An overall increase in population has meant that much communal land, formerly used by pastoralists as dry-season grazing, has been appropriated by governments for irrigation and/or dryland farming purposes, often without any form of compensation.

- Integration of pastoralism into the overall economy has not proceeded very far or easily.

- It has proved difficult and expensive for governments to provide pastoralists with the type of services provided to other communities; such as adequate transport, markets, veterinary and human health and education.

- There are few investment opportunities within the system and surplus capital is invariably invested in livestock, increasing the possibility of overstocking.

Despite the decline that has occurred and the very difficult problems encountered within the pastoral system, there are rational economic reasons for retention of it in the drier regions of the tropics and subtropics. In the past, some pastoralist societies possessing superior military strength, held and utilized land for pastoral purposes that could be used more effectively and productively in other ways. In general, such societies have been losing control of these lands and in the future pastoralism is likely to be confined to the drier regions, except where the land can be effectively exploited in no other manner.

If the decline of pastoralism is to be halted and pastoralists are to effectively exploit the drier regions, new ideas and attitudes have to be introduced. Some of these are that:

- In existing pastoralist societies transhumance should be encouraged at the expense of nomadism or semi-nomadism.

- Agreed rules to prevent overstocking and other forms of over-exploitation that can be upheld should be introduced on communal grazings.

• Alternative investment opportunities to livestock be provided in communal grazing areas.

• Some form of insurance against drought and/or the collapse of market prices be introduced for pastoralists.

• New efforts be made to provide essential services, such as the construction of roads using communal labour, the training of pastoralists as veterinary and medical assistants and the provision of boarding schools.

In some regions, particularly in East, Central and South Africa there is an alternative method of exploiting drier regionsgame croppingproposals for which are discussed later.

Shifting Cultivation

It appears inevitable that virtually all shifting cultivation systems will ultimately disappear, probably evolving into more complex and possibly more productive systems.

Ranching

It is unlikely that, with a rapidly increasing population and the extensive nature of cattle ranching, the system will ultimately survive in Asia and in the Pacific Islands. There may, however, be an interim period in which it flourishes as a temporary system following the extensive logging of tropical rainforest in islands such as Borneo in Indonesia and Mindanao in the Philippines.

In Africa ranching systems are only likely to survive in a limited number of drier regions and primarily in the subtropical regions of Southern Africa. Not only is ranching an extensive system that becomes increasingly irrelevant in more humid areas as human populations increase, but in many tropical countries an alternative extensive system already exists in some form of established pastoralism. In addition, there are two other possible alternative systems in those areas where wild game are present. These are game cropping and game-based tourism in scenic regions. A combination of these systems is possible but could be difficult to organize.

In the semi-arid regions of tropical and subtropical America and Australia ranching systems are likely to remain viable. There is, however, some overall economic pressure for them to become more intensive and this can be achieved in a number of different ways (see Chapter 7). It is probable that the 'ranch milking systems' in Latin America are temporary and that ultimately they will be transformed into either dairy farms or beef ranches and that the majority of the very extensive cattle ranches that are so often an end-product of intensive logging operations in Central and South American rainforests will ultimately be replaced by more intensive systems.

Game Cropping

Game cropping systems will probably continue to develop slowly in East, Central and Southern Africa and elsewhere, but will never become major economic systems. In scenic arid and semi-arid regions it is likely that wildlife tourist parks will become more appropriate economic systems to develop. If economic, game cropping could be combined with wildlife tourism, given appropriate precautions (see Chapters 16 and 19).

Sedentary Crop Agriculture with Livestock

With limited crops and forage yields and high population growth, alternative strategies are required in the semi-arid tropics and subtropics. Agricultural strategies could include the introduction of irrigation, new and more productive dryland crops and more effective utilization of crop by-products.

The situation is very different in the humid tropical and subtropical regions. Although population growth may be as high as in the semi-arid regions the continual felling of forest releases land for agricultural purposes, particularly in

Southeast Asia and South America. To date, a major proportion of this land has been used by shifting cultivators and/or extensive livestock farmers and though in the future more may be used for tree crops it is reasonable to assume that on account of population pressure some part will evolve into a rain-fed mixed farming system. Mixed farming systems in the humid tropics can be very productive. A major investigational effort is required, however, to ascertain the most suitable livestock and crops, including forage and pasture species, to utilize in the system and to ascertain how best to manage it in order to exploit its high potential.

As the technology for productive mixed farming in the tropical uplands is already generally available from temperate countries, and highly productive livestock such as temperate-type dairy cattle and sheep can be used, there is every incentive to promote mixed farming systems in the tropical uplands, particularly those producing milk and wool.

Crop Irrigation:
Intensive Cropping with Extensive Livestock.

In regions where multi-cropping of rice is practised, with increased use of fertilizers, herbicides and pesticides, the number and variety of livestock that can be carried on the stubbles is likely to decrease. The total irrigated area in the tropics is, however, increasing quite rapidly and it is likely that opportunities to husband livestock on the stubbles of newly irrigated areas are increasing, possibly as rapidly as opportunities are closing in multi-cropping areas.

Rural Landless and Urban Livestock

Conventional Livestock

As urban centres expand and become more organized it is likely that it will become more difficult for individual families to keep ruminant livestock unless they are a component of an organized production scheme. It is probable, however, that some families will continue to husband a small number of poultry and perhaps pigs.

Microlivestock

Rural migration to tropical cities is forecast to continue and to grow. Under these circumstances the production of microlivestock in urban and peri-urban areas is also likely to increase. At the same time larger scale units will probably evolve in peri-urban areas for the production of rabbits, guinea pigs and snails.

There will also be pressure to increase research into the production of microlivestock and efforts to fully domesticate present semi-domesticated and wild microlivestock, such as the grass cutter and the iguana.

Integrated Production

There appear to be major possibilities for the acceptance and extension of integrated systems, particularly in the wetter tropics. Primary requirements are an increasing population, reducing the availability of land per family, a suitable climatic environment, the availability of required crops, livestock and fish and markets for them, access to limited capital and a farming community willing and able to accept change. Under these circumstances integration of livestock and tree crops, particularly the grazing of livestock under coconuts, has generally occurred only on the larger estates, whilst the integration of fish with crops and livestock has been mainly, but not entirely, a smallholder development.

Almost all tree crops provide some opportunity for integration with livestock and/or crops. A balance must be maintained, however, between tree crop production, forage production beneath the trees and the productivity of the grazed or yarded livestock. Considerable investigational work is still required to ascertain what the balance should be under various combinations of livestock, tree crops, forages, soils and climatic conditions. Some details are provided in Chapter 7 of various forms of integration with cattle.

Alley farming is slowly being accepted as possibly an economic and productive system in some regions of the sub-humid tropics, whilst sugar cane and some other crops grown on a large scale provide numerous and increasing opportunities for the integration of livestock, utilizing by-products of the cropping system.

There appear to be no doubts as to the synergistic effect of the integration of livestock with fish production. To date, however, these effects have been observed in limited experimental and practical field experience. An increase in productivity is not the only or even perhaps the most important factor that the farmer has to consider. If the system is too complex, too labour intensive, or there is a limited financial gain on the capital employed, any gain in productivity may not be worth the extra risk and work involved.

The number of integrated fish/livestock/crop systems and their complexity are only likely to increase slowly. Knowledge of interactions within these systems is limited and a major investigational programme is required. It is probable that the economic necessity to intensify will be what is ultimately required to encourage expansion of these systems.

Ley Farming

The ley farming system is unlikely to be used to any extent in the montane tropical world.

Modern Sector Livestock Production

It is probable that modern sector milk, pig meat, poultry meat and egg production will continue to expand at the expense of more traditional forms of production, though milk production in particular is likely to be organized in far smaller units than those that are usual in temperate countries.

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PART II
HUSBANDRY.

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7
Cattle

Introduction

Although major changes are occurring, the part played by cattle in the life of the indigenous people of the tropics still differs remarkably from the position accorded to them by man in the mid-latitude zones. In the tropics, as elsewhere, cattle are essential as a source of milk and meat, of work and of many by-products of great value; but for a large number of cattle owners these considerations are equal or secondary to the part cattle play in social custom, as a reserve of family wealth and as a mark of respectability and status within the community. The nomad would as soon deplete his breeding herd as the family man in Europe or America would his bank account; the religious Hindu would rather starve to death than eat his cow; and in different ways and to different degrees there are few tropical people who have not some regard for cattle quite apart from their immediate economic use.

Substantial change in the chapter content has been made in this edition. The number of cattle in the tropics and subtropics and their distribution has been updated, while the section on origin has been expanded to include new information. Some additions have been made to the section on breeds. Details of production systems have been updated and comments on the planning and development of beef cattle and dairy enterprises have been restricted to specific requirements in the tropics and subtropics. The section on working cattle is more limited in scope than in previous editions as work, as a product of livestock, is discussed in depth later in Chapter 21.

Numbers and Distribution

During the period 1964 to 1994 the world cattle population increased by about 22% (Table 7.1) to number 1252 billion head. The increase in number during this 30-year period was so much greater in the tropics than elsewhere that for the first time the cattle population of the tropics surpassed that of the cattle population in temperate lands. In 1994 somewhat more than half of the world's cattle were to be found in the tropics; 13.2, 20.0, 17.1, and 0.5% respectively in Africa, the Americas, Asia, and Oceania.

The most rapid increase in cattle number has been in the American tropics (Table 7.1) where vast areas of rainforest have been and continue to be, felled and burnt; ultimately providing large areas of poor pasturage for cattle and other herbivores. There has also been a relatively large, but unevenly spread, increase in the cattle population of tropical Africa, that may ultimately create serious overstocking problems in some countries. In Oceania there has also been a substantial percentage increase in the tropical cattle population, but the increase has been from a low base. The cattle population in tropical Asia is still expanding (Table 7.1), but at a somewhat slower pace than in the other continental tropical zones. The Southeast region of Asia is

Table 7.1 Distribution of cattle in the world. (*Sources*: FAO, 1968, 1995.)

Continent/region	Number of cattle (000) 1964	1994	% increase or decrease 19641994	As % of world total 1964	1994
Africa					
Tropics	106 584	166 295	+56	10.4	13.2
Other	19 237	21 449	+11	1.9	1.7
Americas					
Tropics	145 232	250 353	+72	14.2	20.0
Other	185 481	192 659	+4	18.1	15.4
Asia					
Tropics	180 643	213 654	+18	17.6	17.1
Other	194 174	217 678	+12	19.0	17.4
Europe					
Other	166 592	156 058	-6	16.3	12.5
Oceania					
Tropics	4 170	6 113	+47	0.4	0.5
Other	21 940	28 336	+29	2.1	2.2
World					
Tropics	436 629	636 415	+46	42.6	50.8
Other	587 424	616 180	+5	57.4	49.2
Total	1 024 053	1 252 595	+22		

an exception as in this relatively humid area the cattle population, starting from a low base, has increased by about two-thirds between 1964 and 1994 (FAO, 1968, 1995).

Generally we conclude that major concentrations of cattle are found in the intensive subsistence agricultural regions of the tropics and in the natural grassland areas and that there are fewer cattle in some of the very dry regions and in the humid rainforest areas. The situation in the latter, however, may be slowly changing as the forests are felled and are replaced by grassland and crops.

Origin

The family of animals that includes all types of domestic cattle are known as the Bovidae. They are the dominant family of hoofed mammals and one of the most recent to evolve. There is some disagreement between authorities as to how the genera within the sub-family Bovinae should be classified. One accepted method is depicted in Fig. 7.1. This suggests that all types of cattle, yaks and bison evolved from one group of common ancestors and buffaloes from another. As there is, to date, no continuous fossil record by which the evolution of these groups can be traced the classification in Fig. 7.1 must be considered as an interim one.

The almost universal distribution of wild species of cattle in the temperate, Mediterranean and subtropical climatic zones of Europe, Asia and North Africa as from the Upper Pleistocene period, makes it difficult to ascertain with certainty the original centre(s) of domestication.

There is some knowledge of five species of wild cattle. The *aurochs* or *urus (Bos primigenius)*, the probable ancestral stock of

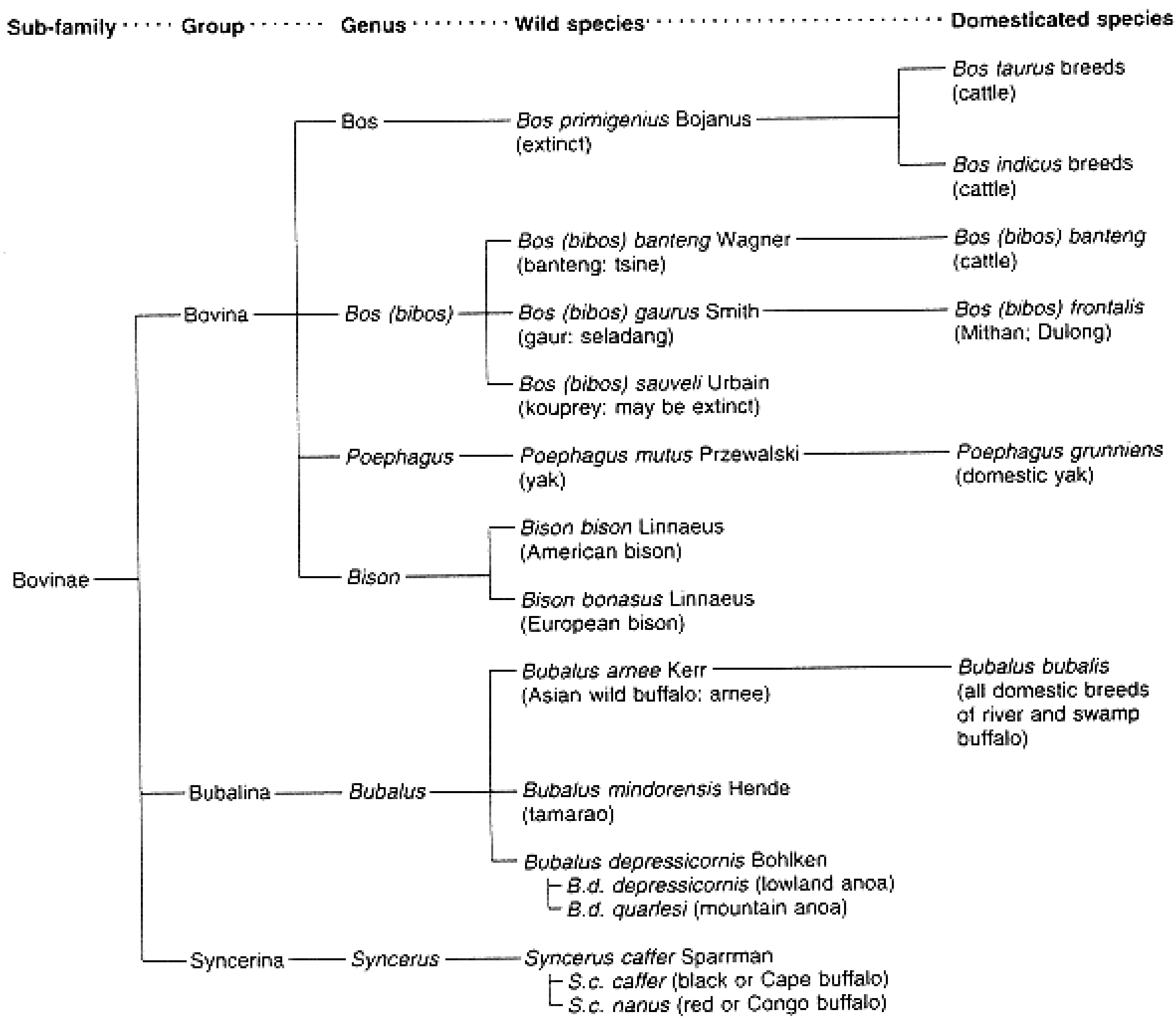

Fig. 7.1
The relationship of the wild and domestic species of the sub-family Bovinae.

most existing *Bos taurus* and *Bos indicus* breeds, had a very wide distribution throughout the Euro-Asian land mass and North Africa within historical times, but is now extinct. It is believed that the last aurochs died in Poland in AD 1627 (Rokosz, 1995). Three other species, the *gaur (Bos (bibos) gaurus)*, the *banteng (Bos (bibos) banteng)* and the *kouprey (Bos (bibos) sauveli)* had a more restricted distribution, being confined to South and Southeast Asia, but were relatively numerous within historical times. At the end of the twentieth century, however, they are much reduced in number. It is probable that all three species have contributed genes to cattle breeds in Southeast and Eastern Asia. One Southeast Asian breed, the *Bali*, appears to be mainly of *Bos (bibos)* spp. origin and many others possess varied percentages of *Bos (bibos)* spp. genes (Namikawa, 1981). A fifth species, the *dulong (Bos (bibos)* spp.), has recently been reported to be extant in the mountains of northwest Yunnan Province in China. It is not known whether it has contributed genes to domestic cattle and is said to be an endangered species. Further details of the wild species of cattle are provided by Payne & Hodges (1997).

The domestication of wild cattle, wherever it occurred, has resulted in the evolution and formation of *Bos taurus*, *Bos indicus* or mixed-blood cattle breeds in Europe, Asia and Africa and crossbreds between *Bos taurus*, *Bos indicus* and *Bos (bibos)* spp. in some regions of Southeast and Eastern Asia. Although *Bos taurus* and *Bos indicus* breeds possess the same number of chromosomes ($2n = 60$) while the *Bos (bibos)* spp. cattle possess ($2n = 58$), crossbreds of *Bos (bibos)* spp. with *Bos taurus* and *Bos indicus* such as the *Bali* of Indonesia, possess $2n = 60$ chromosomes and produce fertile offspring.

The Neolithic revolution ultimately changed the economic life of the majority of mankind from that of hunter/gatherer to that of farmer/stock breeder. It was, however, a slow and erratic process in which plants were domesticated before animals and there is no absolute certainty as to why and where it began. Present available evidence suggests that it was in Western Asia and that the region was a primary centre of domestication, first of food plants, then sheep and goats and by *c*. 8000 BP (before present) cattle. There also appear to have been other primary centres of cattle domestication in Southeast Asia and possibly in Eastern Asia, with secondary centres in Europe, North Africa and Central, East and Southeast Asia.

Possible Centres of Domestication

The term 'primary' centre of domestication is not meant to designate a very specific location, but a region in which similar cultural changes were occurring at approximately the same time and in which it is believed domestication of wild cattle was achieved. It may have been attempted at several localities in the region over a long period of time, with many failures, but ultimately there was a collective success. 'Secondary' centres are regions where wild cattle were domesticated at a later date than in a primary centre, either independently or in a 'copycat' exercise.

Present available evidence suggests that there was one primary centre at which the wild *Bos primigenius*, the ancestor of *Bos taurus* and *Bos indicus* breeds, was first domesticated, but that within that centre there may have been copycat exercises. The domestication of wild *Bos (bibos)* spp. cattle could have occurred at two primary centres.

The primary centre at which *Bos primigenius* was first domesticated is most likely to have been on the lower mountain slopes of the region in Western Asia known as the 'fertile crescent' (Fig. 7.2). It is a region in which either the aurochs or the Asian urus could have been the wild cattle, or in which these slightly different types co-existed. Payne & Hodges (1997) have discussed the evidence for the first domestication of wild cattle and the evolution of at least three different types of domestic cattle in this region. They suggest that the first domestic cattle were of the humpless (*Bos taurus*) Hamitic Longhorn type and that they were domesticated either in the centre-west or north-western areas of the region, possibly 9000 BP. Some 2000 years later the humpless (*Bos taurus*) shorthorn type evolved or was developed, possibly in the centre of the region. It was a smaller animal than the Hamitic Longhorn and it became the dominant type of cattle in the agricultural areas of Mesopotamia, *c*. 7000 BP. In the arid areas northwest of the fertile crescent the humped (*Bos indicus*) zebu type was domesticated, *c*. 5000 BP. This could be classified as a secondary domestication as it apparently occurred several thousand years later than the earliest cattle domestication in the region. It is also possible that it was a domestication of the urus (*Bos primigenius namadicus*) rather than of the aurochs (*Bos primigenius primigenius*). Details of the possible origins of domestic *Bos indicus* cattle are discussed by Payne & Hodges (1997).

Archaeological evidence suggests that the primary centre of domestication in Western Asia is also where the cattle sledge and the plough originated *c*. 6500 BP, and where dairy farming was

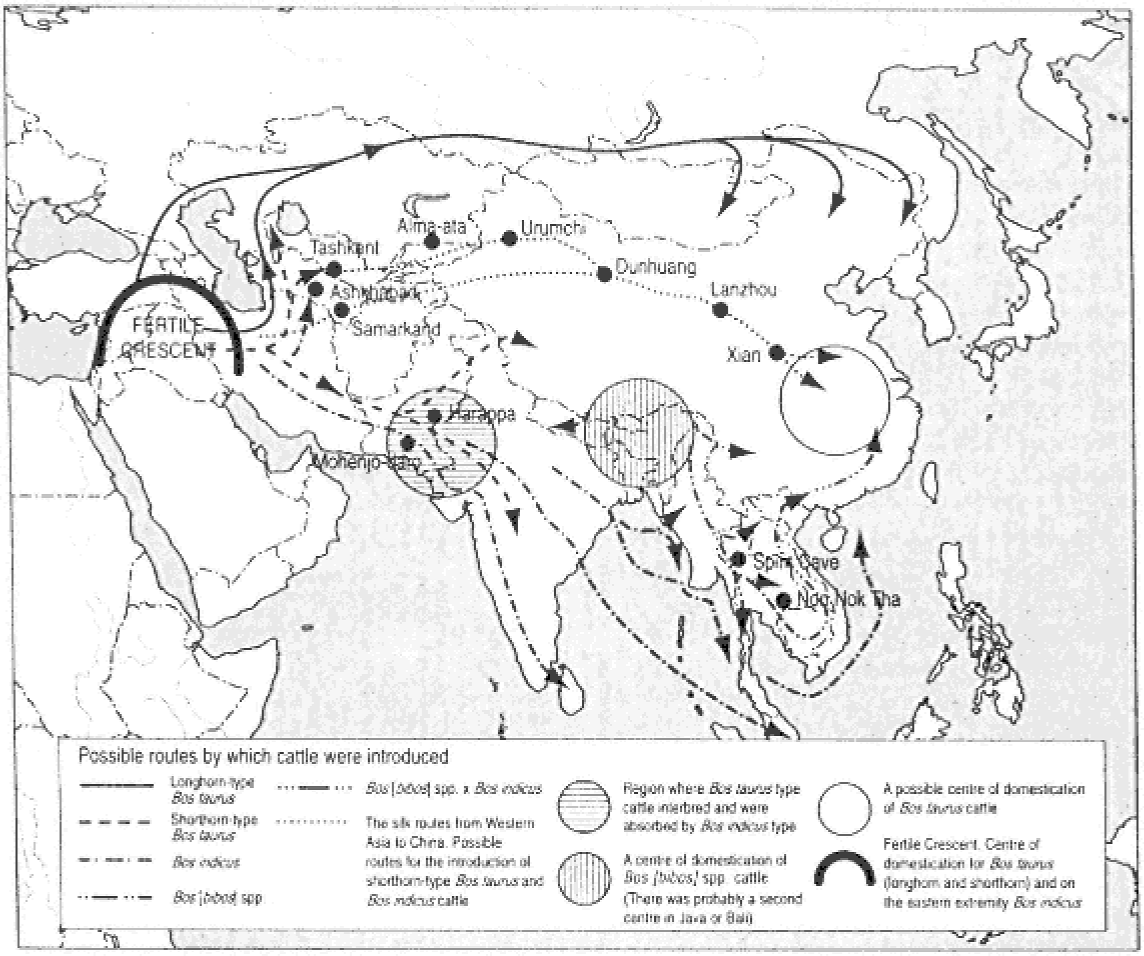

Fig. 7.2
Possible routes by which cattle may have been introduced from the 'fertile crescent' in Western Asia to North, Northwest, East, Southeast and South Asia.

first practised, *c*. 6000 BP (Payne & Hodges, 1997). As stated above there were possibly two separate primary centres at which wild cattle of the *Bos (bibos)* spp. type were domesticated. These were northern Thailand and Indonesia. There is evidence that the gaur (*Bos (bibos) gaurus)* was domesticated in northern Thailand *c*. 6000 BP and as it is unlikely that there was any communication between peoples in Western and Southeast Asia at that time, northern Thailand should be considered a primary centre of domestication. The available evidence suggests that the banteng (*Bos (bibos) banteng)* was domesticated in eastern Java, Bali or an adjacent island of Indonesia. The period at which it occurred is as yet unknown and although there could have been contacts between northern Thailand and Indonesia, no evidence is available, and it must be assumed at the present time that this was also an independent primary domestication.

Asia

Cattle first domesticated in Western Asia were ultimately taken by migrating peoples northwestwards into Europe, northeastwards into Central Asia and beyond, southeastwards into the Indian sub-continent, southwards into the

Arabian peninsula and southwestwards into Africa (Fig. 7.2).

Central Asia

Hamitic Longhorn (*Bos taurus*) type cattle from the 'fertile crescent' may have been introduced into Turkmenia, east of the Caspian Sea as early as 7000 BP (Calkin, 1970). Some 2000 years later people owning shorthorn (*Bos taurus*) type cattle in the 'fertile crescent' moved northeastwards from Iraq into Turkmenia and on into Central Asia and Afghanistan, whilst others moved eastwards, south of the Iranian deserts into Baluchistan and on into the Indian peninsula. According to Verdiev (1989) zebu-type cattle were introduced into Turkmenia at a much later date, *c*. 1300 BP. Today, a majority of the cattle in the region east of the Caspian Sea are *Bos taurus* × *Bos indicus* crossbreds.

China

There is definite evidence that all Chinese cattle do not have a common origin, but whether they are the result of introductions, copycat domestication or independent domestication is as yet unproven. Cattle north of the Great Wall, those in the north, central and eastern regions of central China and cattle in south China, appear to have had different origins.

North of the Great Wall existing cattle breeds are of the longhorn, humpless (*Bos taurus*) type. There is no evidence that they were domesticated in China and Linton (1955) stated that their ancestors were introduced from the west, *c*. 4500 BP. It is reasonable to assume that these ancestors originated in Western Asia and had been gradually introduced northwards and eastwards across the Eurasian steppes. The earliest remains of cattle found in central China are dated *c*. 50004500 BP, are of a shorthorn (*Bos taurus*) type that could have been introduced from the west or locally domesticated as the wild *Bos primigenius namadicus* is known to have been present in the region. The possibility of independent domestication is supported by the fact that apparently these cattle were not milked, whereas if they had been introduced from the west it is almost certain that dairy techniques would have been introduced at the same time. The possibility that they were introduced from Western Asia, through some Central Asian route, must however, still be considered (Payne & Hodges, 1997), as the majority of cattle in Tibet and western Sichuan are of the shorthorn (*Bos taurus*) type. Today south Chinese cattle are of the thoracic-humped (*Bos indicus*) type with some *Bos (bibos)* spp. genes (Chen, 1995). It is likely that the first domestic cattle in south China were of *Bos (bibos)* spp. origin as such cattle were already extant in Southeast Asia, but after 3000 BP they were gradually upgraded to crossbred zebu types by peoples introducing zebu (*Bos indicus*) cattle from Southeast Asia, that had originated in the Indian sub-continent.

Philippines.

The first cattle in the Philippine islands were introduced from China or Southeast Asia. Bautista (1986) stated that there was no evidence of the presence of domestic cattle or carabao (*Bubalus bubalis*) in the country until about 1000 years ago. The surprising fact is that indigenous Philippine cattle possess a relatively high percentage of *Bos (bibos)* spp. genes (Namikawa, 1981), though the gaur and the banteng never existed in that country. This suggests that cattle must have been introduced from China and/or Southeast Asia at a time when the breeds of cattle in those regions possessed a higher proportion of *Bos (bibos)* spp. genes than they do at the present time. After the Spanish conquest (*c*. AD 1521) longhorn (*Bos taurus*) type cattle were introduced from the Americas; more recently additional breeds have been introduced from Europe, Asia and the Americas.

India

Bos taurus type cattle from Western Asia were introduced into Baluchistan and on into the northwest region of the Indian sub-continent by cattle-owning peoples some 3000 years after the first domestication of cattle. They were followed by different peoples herding cervico-thoracic *Bos indicus* type cattle; both types being present in the Harappan civilization in the Indus valley, *c*. 4300 BP. The *Bos taurus* type cattle became extinct in the Harappan civilization and elsewhere in India *c*. 3000 to 2800 BP. Possible reasons for extinction are discussed by Payne & Hodges (1997). During the invasion of the northwest region of the Indian sub-continent by Aryans, when the Harappan civilization was destroyed, thoracic humped *Bos indicus* type cattle were introduced. The latter were spread rapidly throughout the sub-continent and their assimilation of surviving *Bos taurus* and cervico-thoracic humped *Bos indicus* type cattle ultimately produced the numerous breeds found in India today. That *Bos indicus* cattle were introduced and not domesticated in India is disputed by some Indian authors, but introduction does not entirely exclude some form of secondary domestication within the sub-continent. The mithan, a *Bos (bibos)* spp., was undoubtedly domesticated in the north of the sub-continent.

Sri Lanka

Only the remains of *Bos indicus* cattle have been found at Neolithic sites. It is unlikely that *Bos taurus* type cattle were introduced into Sri Lanka before the period of European exploration and conquest.

Mainland Southeast Asia

As the majority of cattle breeds in Southeast Asia possess genes from *Bos taurus, Bos indicus* and *Bos (bibos)* spp. (Namikawa, 1981) it is likely that their origins are complex. *Bos (bibos)* cattle were possibly first domesticated in northeast Thailand as early as 7000 BP and certainly by 5500 BP (Higham & Leach, 1971), so that it is possible that cattle were domesticated in Southeast Asia some 2500 years before they were introduced into the Indian sub-continent. The first evidence of the introduction of cattle to Southeast Asia from the Indian sub-continent is *c*. 2500 BP. Indian culture advanced rapidly so that by 1900 BP, there was an Indian state in the Mekong valley followed by similar states in Malaya, Sumatra and Java. Until at least 2500 BP the majority of domestic cattle in Southeast Asia must have been of the *Bos (bibos)* type, but crossbreeding with introduced cattle gradually changed that situation. The possible manner in which Southeast Asian domestic cattle evolved is discussed in some detail by Payne & Hodges (1997).

Indonesia

There is no evidence that there were any domestic cattle in Indonesia prior to the advent of Hindu culture *c*. 1800 BP. If this assumption is correct, Bali cattle have been domesticated for less than 2000 years and domestication could have been of a secondary nature, stimulated by the advent of Hinduism and/or the spread of domestic cattle in mainland Southeast Asia.

The Arabian Peninsula and the Persian Gulf

The Arabian peninsula occupies a strategic position between Africa to the west, the Persian Gulf and the Indian sub-continent to the northeast and east and the 'fertile crescent' to the north, that ensured that it was a region of major importance in the diffusion of domestic cattle from Western Asia to Africa.

Pastoralists herding Hamitic Longhorn (*Bos taurus*) type cattle occupied the Red Sea littoral in the northwest of the peninsula *c*. 6000 BP (Tosi. 1986). They moved slowly southwards and were followed into northwest Arabia by Semitic-speaking peoples herding the smaller shorthorn (*Bos taurus*) type cattle, *c*. 5000 BP. For a period the two types co-existed in the peninsula, then Cushitic speaking peoples crossed the Red Sea and introduced the longhorn cattle to northeast Africa, *c*. 5000 BP. Longhorns then slowly declined in number in Arabia. Zebu (*Bos indicus*) cattle were first introduced into Arabia sometime between 5000 and 3000 BP from Iraq and/or Iran, probably along the east coast of the peninsula. They were established on the west coast *c*. 3000 BP, as they were introduced into Ethiopia from that region *c*. 2500 BP (Brandt & Carder, 1987). Ultimately the zebu replaced shorthorn-type cattle throughout Arabia, except in isolated areas such as Dhofar, where a shorthorn-type breed. the *Quarra*, survived into the twentieth century.

Africa

In Africa wild cattle (*Bos primigenius opistonomus*) appear to have occurred only in the north including the northern region of the Nile valley. There is no doubt that West Asian Neolithic culture influenced communities in North Africa *c*. 8000 BP, so that although the first domestic cattle in Africa were possibly introduced into the Nile valley *c*. 70006500 BP, copycat secondary domestication also occurred. The first recorded to date was at Capéletti in Algeria *c*. 5100 ± 150 BP (Roubet, 1978).

The overall scenario (Fig. 7.3) for cattle introduction and domestication in North Africa, including the northern Nile valley, suggested by Payne & Hodges (1997), is as follows:

• Hamitic Longhorns from Western Asia were the first cattle to be introduced into Africa, though in limited number.

• Other introductions of Hamitic Longhorn cattle occurred, some directly across the land connection between Asia and Africa, others via Southern Europe to Tunisia; the latter possibly being the major source of the longhorn cattle depicted in rock drawings in the central Sahara and of introductions to West Africa and to Europe via Spain.

• Cattle of the shorthorn (*Bos taurus*) type were domesticated in North Africa in secondary, copycat exercises, possibly at several different sites, but these cattle were not necessarily identical with the shorthorn (*Bos taurus*) type cattle that were domesticated in Western Asia.

• It is not yet known whether shorthorn (*Bos taurus*) type cattle were domesticated in the Nile valley or introduced; present shorthorn-type cattle in Egypt could have resulted from a mixture of introductions from Western Asia and North Africa and/or local domesticates.

• The present indigenous shorthorn-type breeds of North Africa are possibly mainly the descendants of local domesticates.

West Africa

Today, there are three indigenous humpless (*Bos taurus*) breeds of cattle in West Africa, the N'Dama of the forest-savanna region, the West African Shorthorn of the coastal savanna region and the Kuri of the wetland areas around Lake Chad. In addition there are a number of zebu (*Bos indicus*) breeds, found mainly in the drier regions.

Present evidence, including their degree of trypanotolerance, suggests that the first cattle introduced into West Africa were the ancestors of the N'Dama and that introduction occurred *c*. 5000 to 4000 BP. There are no direct clues as to their origin, but they could be dwarfed stock of Hamitic Longhorn origin or crossbred Hamitic Longhorn × shorthorn-type domesticates. Molecular studies suggest that there are *Bos indicus* genes in the N'Dama, but that they have been introduced within relatively recent times.

Ancestors of the West African Shorthorn cattle were also introduced into West Africa possibly from the northeast and the central Sahara. It is considered that they were introduced up to 1000 years later than N'Dama cattle, and as a consequence are less trypanotolerant. It is likely that both the N'Dama and the West African Shorthorn were introduced to West Africa on account of increasing aridity in the central Sahara and North Africa. Dwarfing of the N'Dama and, particularly of the West African Shorthorn, appears to have occurred since their arrival in West Africa and this may have been due to severe mineral deficiencies in the soils. The Kuri of the Lake Chad wetlands, though humpless and longhorned, possess very special characteristics, such as large, lightweight, porous horns that assist them to adapt to the wetland environment. They are possibly a remnant breed of a type of Hamitic Longhorn that were more numerous in the past when there were very extensive wetlands in the central Sahara.

Zebu cattle are relative newcomers to West Africa. They were initially introduced into

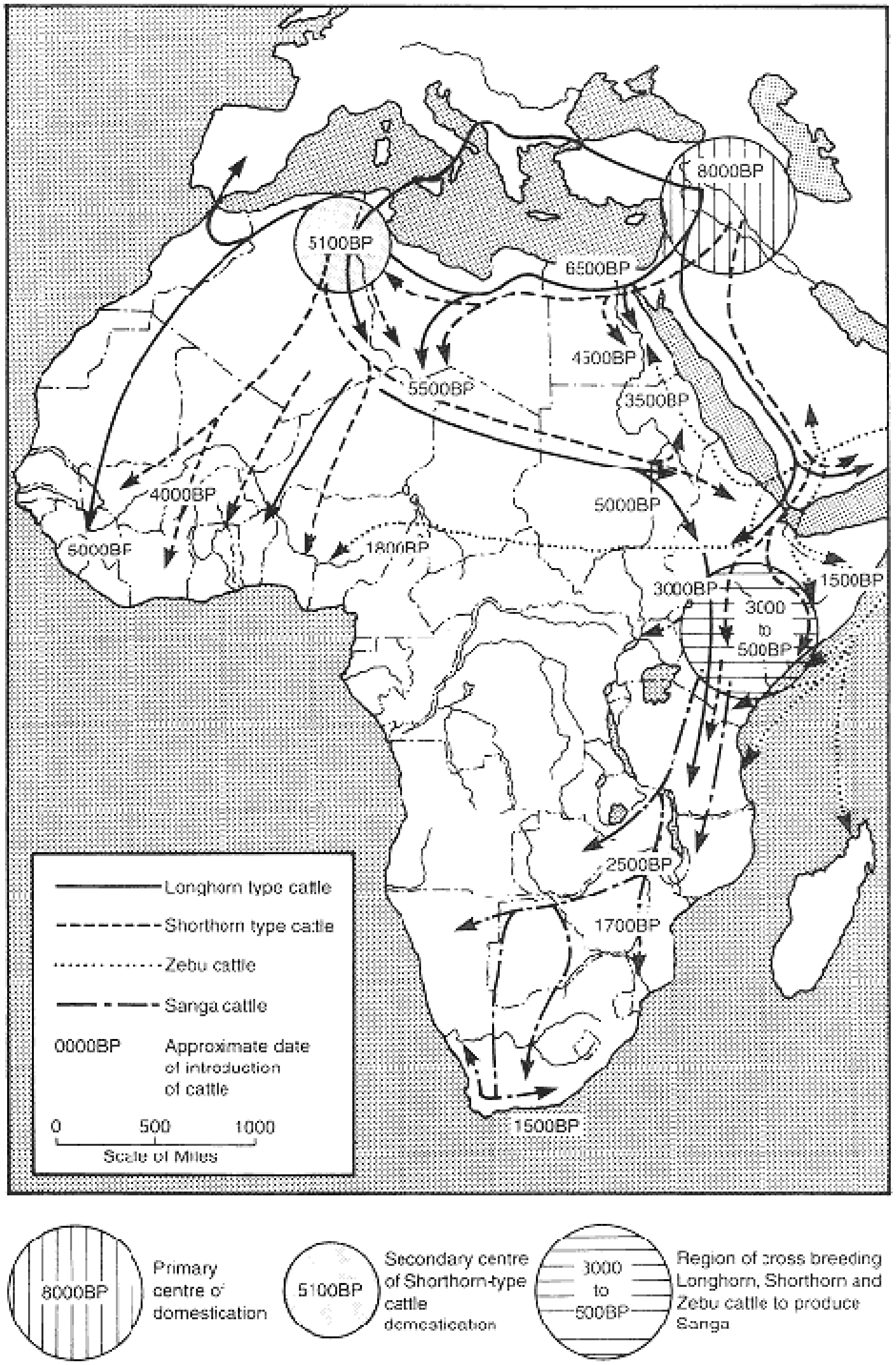

Fig. 7.3
Possible routes by which cattle may have been introduced to North, West, Northwest, East, Central and South Africa.

Northeast and East Africa at least 4000 years ago, but did not appear in West Africa until *c*. 1800 BP. They have been gradually introduced westwards (Fig. 7.3), assisted by two major factors. The increasing aridity of the climate and the deterioration of the environment in the Sahel favoured the introduction of the zebu, as they are superior to longhorn and shorthorn (*Bos taurus*) cattle in withstanding drought conditions. The second factor is that Yemenite pastoralists and other Arab peoples migrated into Africa in number and brought their zebu cattle with them. These people slowly migrated westwards, across a zone within 12° to 14°N latitude as far as Lake Chad. The Kanuri, a people now residing in the region, are considered to originate from inter-marriage between Yemenite Arabs and the Berbers.

Today, the zone between latitudes 12° to 14°N separates the regions to the north in which zebu cattle can be utilized from those to the south and west grazed by peoples with humpless and sanga cattle. The zebu introduced from the east has interbred with the *Bos taurus* types of cattle and some results of the crossbreeding are still evident in present breeds. The Shuwa, a shorthorned zebu, still exhibit some West African Shorthorn characteristics, while the lyre-horned zebu breeds of the Fulani pastoralists, such as the Red Bororo, appear to be the result of early upgrading of longhorn-type cattle by the introduced zebu cattle.

Northeast Africa

As aridity increased in the central Sahara *c*. 5500 to 4500 BP, peoples with their cattle began to migrate from the region. Apparently they moved northwards towards the Mediterranean littoral, northeastwards to the Fayum, west and southwestwards into West Africa as described in the previous section and eastwards to the central region of the Nile rivers, now known as the Sudan. The remains of both Hamitic Longhorn and shorthorn-type cattle, dated 52005030 BP, have been found at Kadero near Khartoum (Kryzaniak, 1980). It cannot be proved that these cattle were introduced from the west, they could have been brought from Egypt or locally domesticated in a copycat exercise, but it is most likely that their ancestors originated in the central Sahara and that they were introduced to the Nile valley via Darfur. Longhorn- and shorthorn-type cattle were the dominant types of cattle found in the central Sudan region until at least 1500 years ago, at which time they began to be replaced by zebu-type cattle. The evidence is that both types of humpless cattle had been introduced into the southern Sudan by 4000 BP and that they were not replaced by zebu or zebu crossbreds for at least 2500 years. After 4000 BP some proto-Eastern Nilotes in southern Sudan migrated, together with their humpless cattle, eastwards into Ethiopia and southwards towards the northern area of the region now known as East Africa.

As stated in a previous section Cushitic-speaking peoples from Arabia migrated, together with their Hamitic Longhorn cattle, into north and eastern Ethiopia *c*. 5000 BP. Proto-Eastern Nilotes also introduced humpless-type cattle from the east, perhaps 1000 years later. Zebu cattle were first introduced *c*. 2500 BP by Semitic-speaking peoples from Arabia. Ownership of zebu-type cattle probably increased rapidly in arid areas but not necessarily in the well-watered highlands. The introduction of zebu cattle has continued at intervals almost up to the present time so that Ethiopia has become a region in which longhorn-, shorthorn- and zebu-type cattle have been crossed and interbred. Interbreeding has produced new sanga breeds whilst continuous upgrading of the humpless longhorn and shorthorn cattle has produced new zebu breeds.

East Africa.

East and Northeast Africa were regions where sanga cattle first evolved as the result of the interbreeding of longhorn-, shorthorn- and zebu-type cattle (Fig. 7.3); a process that has continued up to the present time.

It is probable that longhorn- and shorthorn-type cattle were first introduced into East Africa 4000 to 4500 years ago from the Sudan and/or Ethiopia and that the majority of their ancestors originated from the central Sahara region, though some may have come from Arabia. Evidence for the presence of the first cattle in East Africa has been found at a number of sites in the northeast of the Lake Turkana basin in Kenya (Barthelme, 1984). One thousand years later, longhorn-type cattle from the Ethiopian Rift Valley had been introduced into East Africa and Cushitic-speaking peoples had introduced cattle, sheep, goats and possibly donkeys into the central highlands of Kenya and into northern Tanzania. At about the same period, zebu cattle that had been introduced into Northeast Africa *c*. 3500 BP, began to be brought, in small number, into East Africa. These cattle thrived rather better than longhorn- and shorthorn-type cattle in hot, dry climates and it is understandable that they flourished outside the highland areas of East Africa, and that importation increased. Introduction of these cattle from Arabia was originally accomplished by migrating pastoralists but later they were introduced from the Persian Gulf and possibly even from the Indian sub-continent by sea traders.

Thus a rather unique situation developed between 3000 and 500 BP. Pastoralists of different ethnic origin introduced longhorn- and shorthorn-type cattle, possibly of somewhat different genetic origin, and zebu-type cattle well acclimatized to the hot arid climates of the East African lowlands. The cattle introductions occurred in regions already populated, in part, by primitive agriculturists and hunter/gatherers and into which, *c*. 2400 BP, groups of dynamic, iron-working Bantu agriculturists migrated from the west. The result was a mingling of peoples and cultures, new migrations and the interbreeding of the various types of cattle to form new breeds known as sanga. It is not suggested that interbreeding, with the formation of new breeds was widespread at any one time. It was possibly a slow and intermittent process that occurred in different localities at different times, culminating in tribal groups migrating together with their cattle.

Probably longhorn cattle, owned by Cushitic and other peoples, were the dominant type in East Africa *c*. 2000 BP. It is also likely that they were the ancestral stock of the longhorned sanga breeds that were introduced into Central and South Africa by pastoral and mixed farming migrants from East Africa. Prior to the introduction of zebu cattle in any number, shorthorn must have replaced longhorn as the dominant cattle type in East Africa. This supposition is supported by the fact that there is historical evidence that until relatively recent times shorthorn-type cattle were being slowly replaced in East Africa by sanga and zebu (Payne & Hodges 1997).

At some time after entering East Africa, and probably over an extended period, some of the iron-working Bantu agriculturists acquired livestock, including cattle, from their pastoralist neighbours. At first the Bantu peoples would have acquired longhorn and shorthorn humpless-type cattle, but in due course they also acquired zebu, as the latter were being introduced into East Africa at that time. Indeed, as new owners of cattle, Bantu people were not likely to be inhibited by traditional 'cattle culture' values and may have been, in part, responsible for the crossbreeding of humpless with humped cattle and the evolution of sanga breeds.

Migrations of peoples with their cattle from East Africa southwards probably commenced before 2000 BP, first into Central Africa and then on into South Africa (Fig. 7.3). At first the migrants were likely to have been Sudanic- or Cushitic-speaking peoples and their cattle were of the longhorned sanga-type but later these migrants were followed by Bantu peoples herding longhorned and shorthorned sanga-type cattle and more recently zebu cattle.

Central Africa

In this text Central Africa includes the countries of Malawi, Zambia, Zimbabwe and Mozambique. Almost all indigenous cattle breeds in the region are of the sanga-type, but there are exceptions. A remnant, dwarf, longhorned breed known as the Binga was originally found in an area adjacent to Lake Kariba and is of interest as its presence demonstrates the furthest point in Southern Africa to which it is known that longhorn, humpless cattle were introduced. The other exception is the Angoni, classified as a zebu breed, though of mixed Sanga × Zebu ancestry (Payne & Hodges, 1997).

Present distribution of different sanga breeds in Central, South and Southwest Africa supports the contention that different peoples herded different types of cattle of different origin and migrated southwards by different routes. Present evidence suggests that longhorned Sanga were the first cattle to be introduced to South Africa by Koisan speaking people but that Bantu peoples also introduced this type of cattle to Central and possibly to Southwest Africa. There seems little doubt that Bantu peoples introduced shorthorned Sanga to eastern areas of Central Africa and to Southeast Africa.

There is some evidence as to the routes by which cattle may have been introduced into Central and Southern Africa. Ford (1960) suggested that three routes were possible. These were that migrants with their cattle:

- followed the mosaic of forest and savanna that developed around the borders of the rainforest of the Congo basin; or

- used the secondary grasslands that had developed as the result of cultivation and the use of fire along the borders of the lower montane forests of the highland areas from Kenya, through Tanzania to Malawi; or

- used the coastal agricultural strip cleared by Arab colonizers using slave labour.

Only the first two routes were open for use by the first migrants who were probably Stone Age pastoralists or agropastoralists as the Arabs did not clear the coastal strip until at least 1500 BP, some time after the first cattle had been introduced to the Cape and iron-working Bantu people with their cattle had reached Central Africa.

Southern Africa

Archaeological evidence suggests that sheep were the first domestic animals to be introduced into the western and southern Cape *c*. 2000 BP and that cattle had been introduced by 1500 BP (Klein, 1986). The present distribution of indigenous cattle breeds and historical evidence suggest that the first cattle introduced to the Cape were of the longhorned sanga type.

According to Ehret (1967, 1968) the linguistic evidence suggests that the peoples who introduced cattle as far south as Botswana and the northern Transvaal spoke languages related to the central Sudanese languages of East Africa, but it is most likely to have been Koisan pastoralists speaking a related language, who ultimately introduced cattle to the Cape. Several routes have been suggested. Details of these are discussed in Payne & Hodges (1997).

After the first introductions cattle were imported by other peoples and by other routes. Iron-working Bantu people arrived in the Transvaal *c*. 1800 BP together with their longhorn Sanga, followed by other Bantu peoples herding shorthorn Sanga. After European settlement cattle were introduced from outside Africa. Today the various types of Sanga introduced by Koisan and Bantu peoples have been so interbred with each other and with cattle of European origin that it is difficult to differentiate the original indigenous breeds.

When Europeans first sighted and landed at the Cape the Hottentot (Koikoi) people, probably descendants of the Koisan-speaking peoples who first introduced cattle, owned large herds of big, reddish-coloured cattle that they used for riding, pack purposes and meat. In AD 1652 the Dutch East India Company acquired their first herd of these cattle in order to provide meat for the provision of their ships. Later, Dutch settlers by purchase and theft, transferred many thousands of these cattle to their ownership. It was from these cattle that the Africander breed was developed first to provide superb trek oxen and more recently for beef production.

The Americas

The first introduction of cattle into the Americas was probably by the Vikings, landing cattle in Nova Scotia (Fig. 7.4) *c*. 1000 BP. The introduction failed.

Fig. 7.4
Diagrammatic presentation of major routes by which cattle were first introduced into North, Central, and South America.

Spanish Cattle

It was not until the second voyage of Columbus that cattle were established in the Americas. They were landed (in November 1493) at Isabela on the north coast of the island of Hispaniola (Dominican Republic). The cattle had been loaded in Spain and in the Canary Islands and Rouse (1977) considered that they were mainly of the longhorn type and would have exhibited some of the characteristics of the present-day Retinto, Berrenda and Black Andalusian Spanish breeds. After initial set-backs the imported cattle rapidly expanded in number, reinforced by additional importations from Europe. Twenty years after the first introduction cattle had been imported into all the major Caribbean islands and onto the mainland in the Darien region of Panama. In 1521 the first cattle were landed on the North American mainland at Tampico, Mexico. These cattle multiplied so rapidly that by 1545 cattle herders were crossing the Rio Grande into what is now the State of Texas, 1000 km north of the region into which they were first introduced. The same rapid increase in cattle population occurred in South America. Cattle were first landed at Santa Marta, Colombia in 1524 and 30 years later they were being introduced into the Argentine. This phenomenal increase in cattle numbers in the Americas during the sixteenth century has been detailed by Rouse (1977).

The salient features in the history of the introduction of Spanish cattle and the development of the cattle industry in Spanish-speaking America are that:

- a very limited genetic base existed for the development of criollo (Spanish Latin American) breeds;
- during three centuries of almost complete isolation from exotic cattle introductions, local breeds or ecotypes evolved that were well suited to a number of very different environments; and
- there was little specialization; cattle were normally used to provide work and meat, seldom milk, universally to produce hides and tallow.

Although the limited genetic base may have restricted the development of very productive breeds in Spanish America it did not restrict the astonishing ability of the Criollo to adapt to a variety of diverse environments. From the original cattle introduction have evolved such different breeds as the Chinampo of arid, Baja California, the Blanco Orejinegro of Antioquia, Colombia that is resistant to the ravages of the *nuche* or ox warble fly and the Bolivian Criollo that survives in the cold, harsh uplands of the Andes.

Criollo cattle from the Caribbean were introduced into Florida and the Gulf coast of North America, whilst from Mexico they were introduced across the Rio Grande into what is now Texas and the southwestern states of the United States. Even in 1850 virtually all cattle in the State of California were of the criollo type.

Unfortunately, in more recent times the adaptability of criollo cattle has been generally ignored and their lack of productivity has been stressed. Throughout Spanish America more productive, exotic breeds have been introduced and indiscriminate crossbreeding on a continental scale has endangered the existence of many criollo breeds (Payne & Hodges, 1997).

Portuguese Cattle

The first recorded introduction of cattle into Brazil by the Portuguese was in 1532 when de Sousa founded a colony at São Vicente on the northeast coast of South America. During the next 50 years a prosperous sugar plantation industry developed and slave labour from Africa was introduced. It is not know whether cattle were introduced from West Africa at this time.

A similar adaptation of introduced Portuguese cattle breeds took place as had occurred in Spanish America. The Brazilian-adapted cattle being known as Crioulo. On account of physical barriers, such as the extensive rainforest, there was little contact between the Brazilian and Spanish American cattle owners. There was, however, one major difference, Asian zebu cattle were imported into Brazil at least 100 years before they were introduced into Spanish American countries.

British and Other European Cattle

Payne & Hodges (1997) provide some detail as to the importation of British, French and other European cattle into the Americas. Towards the end of the eighteenth and the beginning of the nineteenth century British-type cattle from the north were introduced further and further southwards and westwards within the United States. They were eventually used to upgrade criollo cattle in southern and western states, particularly Texas. It was not a totally successful strategy and towards the end of the nineteenth century a new breeding policy gradually evolved. This was the crossbreeding of the upgraded cattle with Zebu, the majority of these being the descendants of zebu cattle imported into Brazil from India. This was a successful policy and by the mid-twentieth century a number of stabilized or semi-stabilized European × Zebu crossbred breeds had emerged that were reasonably pro-

ductive in tropical and subtropical environments. In the latter part of the twentieth century the southern and southwestern regions of the United States ceased to import breeding cattle and commenced to export such breeds as the Santa Gertrudis to the tropics. A fascinating reversal of role.

African Cattle

Santiago (1967) stated that in 1524 cattle were imported into Brazil from Senegal, that these cattle were likely to be of the N'Dama type and that sporadic importation from Africa continued for at least the next two centuries. It is known that in the early nineteenth century cattle were introduced from East Africa and Madagascar. It is presumed that all these introduced cattle interbred with the local Crioulo and lost their identity.

N'Dama were also imported into St Croix in the Caribbean Virgin Islands (18601880), where they were interbred with Red Poll cattle, the resulting crossbred being known as the Senepol or Nelthropp. Cattle of this breed have recently been imported into Florida for assessment and crossbreeding purposes.

Africander cattle from South Africa were introduced into the United Sates (King Ranch, Texas) in 1931 and into Brazil (São Paulo) in 1939 for assessment, but no new breeds have resulted from these importations.

Asian Cattle

The earliest recorded introduction of Asian cattle into the Americas was to Brazil in 1813 when two zebu-type animals were imported from India. It is likely, however, with Portuguese vessels plying between South and Southeast Asia, Portugal and Brazil, that there were earlier importations. Payne & Hodges (1997), have provided some details as to importation of Asian cattle into the Americas. At least 6000 breeding cattle from no less than 14 Indian breed-types were imported into Brazil between 1813 and 1964, though only three zebu breeds, the Gir, the Kankrej (Guzera) and the Nellore and one composite breed, the Indú-Brazil, are at present officially recognized.

The first zebu cattle were imported into Jamaica from India in 1850. During the second half of the nineteenth century zebu cattle were introduced into almost all Caribbean countries.

A South Carolina doctor introduced the first zebu cattle (two Mysore bulls) into North America in 1849. The bulls and their progeny were lost during the Civil War. During the next 50 years a number of importations of zebu cattle were made (Payne & Hodges, 1997) and by 1906 progressive ranchers in Texas had accumulated sufficient evidence to convince themselves that there was, under their environmental conditions, an advantage in using the Zebu for crossbreeding purposes. A major import of Nellore, Kankrej, Krishna Valley and Gir bulls from India was made at this time. Later importations were from Brazil via Mexico (Payne & Hodges, 1997). Ultimately a number of new breeds were formed in the southwestern United States. These included the Santa Gertrudis (Zebu × Shorthorn), the Beefmaster (Zebu × Hereford × Shorthorn), the Brangus (Zebu × Angus) and the Braford (Zebu × Hereford) and during the latter part of the twentieth century cattle from these new breeds have been exported to the Caribbean, Latin America, Africa, Asia, Australia and Oceania.

A large-scale experimental programme to ascertain whether the introduction of genes from the Red Sindhi breed would improve the acclimatization and milk production of Friesian, Jersey and Brown Swiss milking cattle in the subtropical regions of the United States was commenced in the 1950s. It was ultimately concluded that the introduction of zebu genes into the dairy breeds was not as useful as had been their introduction into the beef breeds.

Australia and Oceania.

There were no cattle in Australia or in any other South Pacific country before the advent of European exploration and settlement. Introduction of cattle to Australia commenced towards the end of the eighteenth century; the first recorded introduction being the landing of two bulls and three cows of unknown breed at Sydney Cove in 1788. Details of cattle introduction throughout the nineteenth century are provided by Payne & Hodges (1997) and although the majority were of British breeds, there were introductions of Zebu. The introduction of small and isolated groups of zebu cattle, however, had little effect on the development of the mainstream cattle industry. It was not until the twentieth century that the problems of cattle production in the subtropical and tropical regions of Australia were considered.

Interest in the use of the Zebu grew very slowly and in 1931 the Council for Scientific and Industrial Research (CSIR), in association with four major Queensland cattle breeders, proposed the import of purebred Zebu from the United States to be used in crossbreeding and upgrading programmes. It was apparent from the results that the use of Zebu for upgrading British breeds of cattle in the subtropical and tropical regions was a desirable and productive practice; as it had been shown to be in Texas a good half-century earlier. Crossbreeding commenced on a large scale and American breeds such as the American Brahman and the Santa Gertrudis were imported in number.

At about the same period the Commonwealth Scientific and Industrial Research Organisation (CSIRO) became interested in the possibility of using crossbred zebu cattle for dairying. Ultimately two useful and productive composite breeds emerged, the Australian Milking Zebu and the Australian Friesian Sahiwal. It is possible that the Australian decision to use crossbred milking cattle as opposed to the American decision to retain purebred European-type milking cattle has been due to the harsher nature of the environments in regions where Australians wish to produce milk.

Towards the end of the eighteenth century and throughout the nineteenth and twentieth centuries introductions of tropical cattle have been made into the tropical islands of the Pacific. Some details of introductions into the Hawaiian, Fijian and Society islands are discussed by Payne & Hodges (1997). European-type and zebu cattle have been introduced and in general zebu or crossbred (*Bos taurus* × *Bos indicus*) are now used for beef production whilst European-type milking cattle with or without a limited infusion of zebu genes are used for dairy production.

Types of Tropical Cattle

More types and breeds of cattle are to be found in the tropical and subtropical regions of the world than in the temperate zones. The distribution of the major types is shown in Fig. 7.5.

Humpless or *Bos taurus* type cattle may be completely acclimatized and of ancient origin such as the N'Dama and Dwarf Shorthorn of West Africa, the Kuri of the Lake Chad area of Africa and the Oksh of Western Asia, or imported into the tropics in historical times and more or less acclimatized such as the Criollo cattle of Spanish Central and South American countries, the Crioulo of Brazil and the Creole of Mauritius. In addition modern unacclimatized European breeds such as the Friesian and the Jersey have been imported into the tropics in recent times, often with disastrous results.

Humped or *Bos indicus* type cattle may also be of fairly ancient origin, as they are in Western Asia, the Indian sub-continent and some areas of Northeast Africa; imported in historical times as in West Africa and some regions of Eastern Africa; or imported recently such as the zebu cattle of the Americas and Oceania that include the recently developed American Brahman and the Indu-Brazil breeds.

Wherever *Bos taurus* and *Bos indicus* cattle were introduced into the same region there has been crossbreeding. In Africa it occurred on an extensive scale in the northeast and eastern regions commencing 3000 to 4000 years ago and, as previously stated, the resulting old, stabilized crossbred breeds of cattle are known as 'Sanga'. Major cattle breeds in Central, South and South-

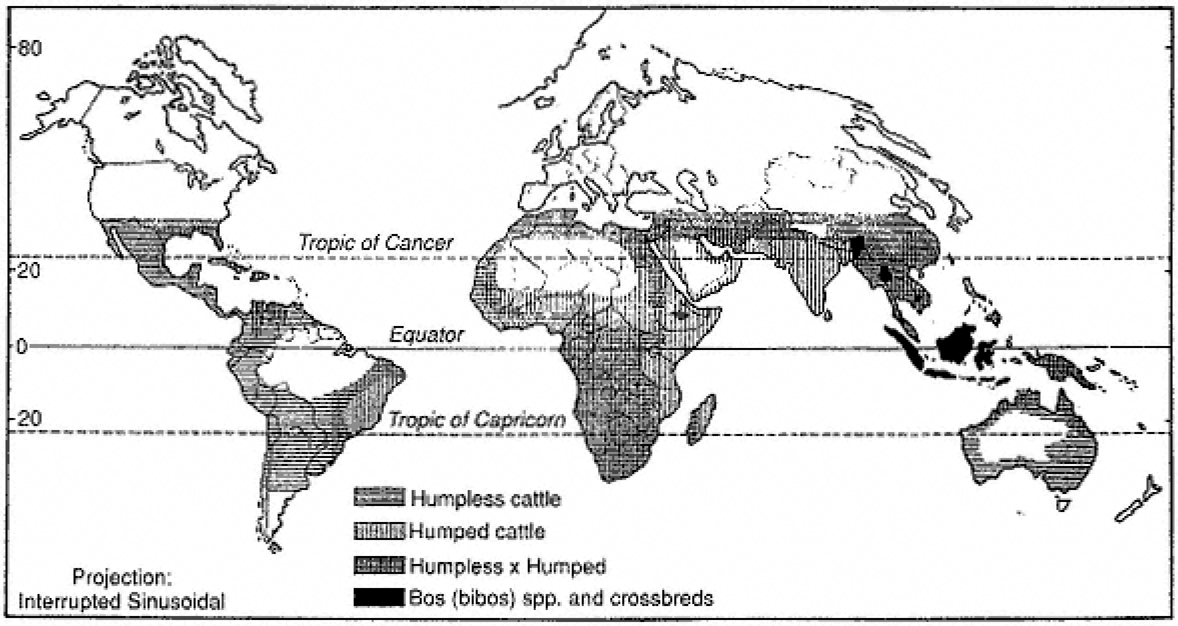

Fig. 7.5
The distribution of major types of cattle in the tropics and subtropics.

west Africa at the present time are of the Sanga type. Within historical times Zebu have replaced longhorn- and/or shorthorn-cattle types in some regions of Western Asia, most of Arabia, many of the lowland regions of Northeast Africa and in the major part of East Africa.

In the twentieth century, particularly in the Americas and Australia, large-scale crossbreeding has been organized in an attempt to provide productive breeds of cattle for tropical and subtropical climates.

In Southeast Asia where the first cattle to be domesticated were probably of the *Bos (bibos)* spp. type, the majority of present breeds are a mixture of *Bos taurus, Bos indicus* and *Bos (bibos)* spp. (Namikawa, 1981) with one breed, the Bali of Indonesia, retaining a large proportion of *Bos (bibos)* spp. genes. In East Asia the situation is even more complicated. There may have been local domestication of *Bos taurus* type cattle but the majority of the cattle appear to be descendants of introduced cattle, with genes from *Bos taurus, Bos indicus* and *Bos (bibos)* spp. sources in all southern and some central breeds and from *Bos taurus* and possibly some *Bos indicus* sources in the north. There is still a lack of information on this great diversity of breeds in the tropics and subtropics and insufficient is known about their general characteristics, their genetical make-up and their potential productivity. The most recent collective information is provided by Maule (1990) and Payne & Hodges (1997).

Although the classification provided below is tentative and there has been some modification of the details that were published in the fourth edition, we believe that it provides a useful guide that can and will be modified as further information becomes available. Breeds have been classified according to the continent of recent origin, within continents on a regional basis, within regions on a type basis and within type on a 'major characteristic' or utility basis. The major types recognized are humpless (*Bos taurus*), humped (*Bos indicus*), cattle of crossbred origin and cattle of *Bos (bibos)* spp. origin. Cattle of crossbred origin are subdivided into three groups. Group A comprises the more or less established indigenous breeds that are considered to have originated from past crossbreeding. The second group B consist of what Mason & Maule (1960) describe as 'intermediate breeds' that may not be particularly recent in origin, but are apparently still in a state of flux. Group C includes breeds of recent and very recent origin whose evolution and formation has been deliberately planned.

Classification of Breeds

Asia

Western Asia

(1) *Humpless cattle*

Cyprus: Dofar; Eastern Red; Jaulan; Kurdi; Oksh: Socotra.

(2) *Humped cattle*

Afghan: Mazandarani; South Arabian Zebu.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Damascus; Iranian; Iraqi; South Anatolian Red.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Israeli-Friesian.

Indian sub-continent and Sri Lanka

(1) *Humpless cattle*

No indigenous breeds in this category.

(2) *Humped cattle*

(A) *Dairy types*
Red Sindhi; Sahiwal.

(B) *Dairy/draught types*
Gir; Tharparkar.

(C) *Draught/dairy types*
Bhagnari; Deoni; Gaolao; Hariana; Kankrej; Krishna Valley; Ongole; Punganur; Rath.

(D) *Draught types*
Amritmahal; Bachaur; Bargur; Bengali; Dangi; Dhanni; Hallikar; Jellicut; Kangayam; Khillari; Kumauni; Ladakhi; Lohani; Malvi; Mampati; Mewati; Nagori; Nimari; Ponwar; Sinhala; Tamankaduwa.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Siri.

(B) *Intermediate*

No indigenous breeds in this category.

(C) *Recent*
Hatton; Karan Fries; Karan Swiss; Sunandini; Taylor.

(4) *Cattle of* Bos (bibos) *spp. origin*

Gayal.

Southeast and East Asia

(1) *Humpless cattle*

No indigenous breeds in this category.

(2) *Humped cattle*

South Chinese Zebu; Sumba Ongole; Taiwan Zebu.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Bali; Batangas; Burmese; Cambodian; Chinese Yellow; Javanese; Kedah-Kelantan; Madura; Philippines Native; Sumatran; Thai; Vietnamese.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Grati; Java Ongole; Local Indian Dairy.

(4) *Cattle of* Bos (bibos) *spp. origin*

Dulong.

Africa

North Africa

(1) *Humpless cattle*

Brown Atlas; Libyan.

(2) *Humped cattle*

No indigenous breeds in this category.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Egyptian.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Meknès Black Pied; Thibar.

West Africa

(1) *Humpless cattle*

Kuri; N'Dama; West African Shorthorn.

(2) *Humped cattle*

(A) *Shorthorned Zebu*
Azaouak: Maure; Shuwa; Sokoto Gudali.

(B) *Medium-horned Zebu*
Adamawa; Diali.

(C) *Lyre-horned Zebu*
Senegal Fulani; Sudanese Fulani; White Fulani.

(D) *Long lyre-horned Zebu*
Red Bororo.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Bambara; Borgou; Djakoré.

(B) *Intermediate*
West African Shorthorn × Zebu crossbreds: Méré; Sanga; Kuri × Zebu crossbreds: Jatko; Kanem; Kilara; Toubou

Northeast and East Africa

(1) *Humpless cattle*

Sheko.

(2) *Humped cattle*

Abyssinian; Boran; Karamajong; Small East African Zebu; Small Somali Zebu; North Sudan Zebu.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Danakil; Nilotic.

(B) *Intermediate*
Aradó; Fogera; Horro; Jiddu; Kuri; Nganda.

(C) *Recent*
Mpwapwa.

Central Africa

(1) *Humpless cattle*

No indigenous breeds in this category.

(2) *Humped cattle*

Angoni.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*

(i) *Longhorned Sanga*
Angolan; Ankole; Barotse; Govuvu; Tuli.

(ii) *Shorthorned Sanga*
Mashona; Tonga.

(B) *Intermediate*
Alur; Baila; Matabele; Nkone

(C) *Recent*
Kisantu; Mateba.

Southern Africa

(1) *Humpless cattle*

No indigenous breeds in this category.

(2) *Humped cattle*

No indigenous breeds in this category.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*

(i) *Longhorned Sanga*
Damara; Ovambo; Tswana.

(ii) *Medium-horned Sanga*
Basuto; Nguni.

(iii) *Lateral-horned Sanga*
Africander.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Bonsmara; Drakensberger; Holmonger.

African Offshore Islands

(1) *Humpless cattle*

Mauritius Creole.

(2) *Humped cattle*

Madagascar Zebu.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Baria.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Rana; Renitelo.

The Americas

North America

(1) *Humpless cattle*

Florida Cracker; Longhorn.

(2) *Humped cattle*

Brahman.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
No indigenous breeds in this category.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Barzona; Beefmaster; Braford; Brangus; Charbray; Red Brangus; Santa Gertrudis.

Central America and the Caribbean

(1) *Humpless cattle*

Barroso; Chinampo; Cuban Criollo; Dominican Milking Criollo; Doran; Mexican Dairy Criollo; Senepol; Tropical Dairy Criollo.

(2) *Humped cattle*

Cuban Zebu; Jamaican Brahman.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
No indigenous breeds in this category.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Jamaica Black; Jamaica Hope; Jamaica Red; Romana Red; Siboney.

South America

(1) *Humpless cattle*

Argentine Criollo; Blanco Orejinegro; Bolivian Criollo; Brazilian Polled; Caracú; Casanareño; Chino Santandereano; Costeño Con Cuernos; Crioulo Lageano; Curraleiro; Ecuador Criollo; Hortón del Valle; Limonero; Pantaneiro; Romosinuano; San Martinera; Yacumeño.

(2) *Humped cattle*

Brazilian Gir; Guzerá; Indú-Brazilian; Nelore.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
No indigenous breeds in this category.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Canchim; Carora: Lucerna; Ocampo; Pitangueiras; Tabapuã.

Australia

(1) *Humpless cattle*

No indigenous breeds in this category.

(2) *Humped cattle*

Australian Brahman; Australian Sahiwal.

(3) *Cattle of crossbred origin*

(A) *Stabilized indigenous*
Australian Africander.

(B) *Intermediate*
No indigenous breeds in this category.

(C) *Recent*
Australian Braford; Australian Brangus; Australian Charbray; Australian Friesian Sahiwal; Australian Milking Zebu; Belmont Red; Droughtmaster.

Representative and/or Important Tropical Breeds

We do not claim that the above classification includes every tropical or subtropical cattle type considered to be a breed. Some may still be evolving, whereas others, whilst stated by their owners, sponsors or local authorities to be breeds, have never been established or internationally accepted. We do claim, however, that the majority of existing breeds are classified, including a number not included in the fourth edition of this book. As it is not possible in an introductory text to discuss in detail all, or even a majority, of the breeds listed, details are provided of representative and/or economically important breeds.

Some details of the average performance of some of the breeds described below are provided in Tables 7.2 and 7.3. No references are provided as the data cited have been obtained by the collation of information from many different sources. For further information on tropical and subtropical breeds and their average performance and productivity the reader should consult Joshi & Philips (1953), Joshi *et al*. (1957), Santiago (1967), Rouse (1970a, 1970b, 1973, 1977), Maule (1990), Aboagye *et al*. (1994), Felius (1995) and Payne & Hodges (1997).

Asian Breeds

Bali (*Bibos Banteng Wagner*) (Fig. 7.6).

Synonym: Balinese.

Origin and Habitat

This breed was considered to be a domesticated banteng (*Bos (bibos) banteng*) (Aalfs, 1934; Maule, 1990) originating from wild banteng that, according to Wallace

Table 7.2 Data on liveweight, height at withers and carcase dressing percentage of some representative tropical breeds.

Breed	Liveweight (kg)				Height at withers at maturity (cm)		Approximate carcase dressing percentage
	At birth		At maturity				
	Male	Female	Male	Female	Male	Female	
African cattle							
Africander	30	28	454907	363544	130142	127135	5964
Angoni	20	18	272726	181472	124137	114135	6164
Ankole	1722	1521	350500	200400	117147	117132	4555
Boran	25	23	318680	259454	117147	114127	5457
Mashona	23	21	363635	159408			
N'Dama	16	14	222419	210353	94119	89112	4056
Small East African Zebu (Bukedi)	1820	1620	254450	270318	102122	99107	4253
Sokoto	25	24	499544	333	137	127	50
Sudanese	2325	2125	300500	250350	142147	130137	4050
West African Shorthorn	25	23	120450	12035	90117	79114	
White Fulani	2025	2023	250350		152	137	5255
American cattle							
American Brahman		29	700900	450650			
Romo-Sinuano		30	600800	500700			5860
Santa Gertrudis		31	9001100	650850			
Asian cattle							

Bali			350400	250300	127	117	5058
Damascus	2142	31	136318	136272	130160	119150	
Gir	2526	2124	544	386	122142	114145	
Hallikar			340	227	135142	119	
Hariana	2325	2224	363544	356	132155	127140	
Ongole	2730	2427	544612	431454	142155	122145	
Red Sindhi	1822	1522	318454	249340	124145	102127	
Sahiwal	2224	2022	454590	272408	127	117130	
Thai			345500		119	109	
Tharparkar	2224	2124	363454	227340	127132	124127	

Table 7.3 Data on age at first calving and the milk production of some representative tropical breeds.

Breed	Age at first calving (months)	Milk production per lactation (kg) Normal range	Maximum	Length of lactation (days)	Fat (%)	Calving interval (months)
African cattle						
Angoni		630800		245270	5.7	
Ankole	4260	318817	900	212239	3.07.01624	
Boran	3652	4541814	3000	139303	4.16.81114	
Mashona		218499		180270		
N'Dama	2772	150270	500	150300	6.57.01442	
Small East African Zebu (Bukedi)	2561	227998	2000	223280	4.77.11114	
Sokoto	36	4541361	2000	230283	5.8	15
Sudanese	2454	4542723	5000	168339	4.75.51224	
West African Shorthorn	3048	120360		120180		1224
White Fulani	3648	6351225	2500	190360	5.07.51215	
American cattle						
Jamaican Hope	2733	4541814	9000	250305	5.05.21214	
Asian cattle						
Damascus		15003000	5000	190300	4.05.0	
Gir	3151	12252268	3000	240380	4.54.61416	
Hallikar	3969	2271134		180		14
Hariana	3272	6351497	4500	260320	4.04.81921	
Ongole	3651	11791633	3500	300330	5.1	1618
Red Sindhi	3043	6802268	5500	270490	4.05.01318	
Sahiwal	3043	11343175	4500	290490	4.06.01318	
Thai		260580				
Tharparkar	2447	6802268	4500	280440	4.24.71418	
Australian cattle						
Australian Milking Zebu		14452647	5000	305	4.84.9	

(1962) were still to be found in the mountains of Bali when he visited the island in 1856.

Investigations by Namikawa (1981) and others have shown. however, that although Bali cattle are primarily a *Bos (bibos)* type, they possess some genes similar to those of *Bos taurus* and *Bos indicus* cattle, so that the breed should be classified as a stabilized indigenous crossbred. They probably originated in Bali and are found today in Bali, Lombok, Timor, Flores, Sulawesi, East Java and Kalimantan in Indonesia and in small numbers in Sabah. They have been exported to Malaysia, the Philippines and Hawaii. There is also a feral population of several thousand in the Cobourg peninsula of the Northern Territory of Australia, to which the cattle were imported from Bali in 1849 (Calaby, 1975).

The climatic environment throughout the region is generally humid and tropical.

Physical Characteristics

The Bali is a medium-sized, deep-chested, fine-legged animal. The coat colour is usually red, though a golden colour and deep brown are known, while being uncommon. The muzzle, feet and switch are black and the legs are white up to the hocks, and there is white under the thighs and a very distinct white oval patch on the hindquarters. There is always a distinctive black line along the back, commencing at the shoulders and ending above the tail. The

Fig. 7.6
Bali.

male is darker than the female, the coat colour becoming dark brown to black at maturity. At birth the calves of both sexes possess a golden to reddish-brown coat with typical light spots on the back of the legs. The black colour disappears and the reddish-brown coat colour returns if the male is castrated. The hair is short, fine and smooth. The skin is pigmented and fine. The head is broad and short, with a flat poll; the ears are of medium size and erect. The horns of the male are large, grow sideways and then upwards, and are pointed. Those of the female are considerably smaller. The male possesses a definite crest and the dewlap is well developed in both sexes. The udder of the female is poorly developed and covered with hair.

Utility

The breed is used for work purposes, but it is also considered to be a good meat animal that possesses a high dressing-out percentage (Table 7.2) (Payne & Rollinson, 1973). It is more fertile than the Zebu and is considered to be superior to the Zebu as a work animal in humid tropical climates. It also demonstrates an ability to thrive on feeds of very low nutritive value.

Damascus (Fig. 7.7)

Synonyms: Aleppo, Damascene, Baladi, Halabi, Halep, Kheisi, Shami.

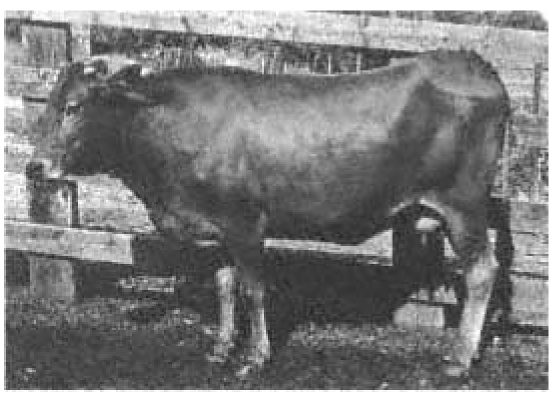

Fig. 7.7
Damascus.

Origin and Habitat

This is a stabilized crossbred between *Bos indicus* and *B. taurus*. The breed appears to have been developed in the

Ghuta, the oasis of Damascus, and then spread to other areas. Cattle of this type are found today in Syria, southern Turkey, Iraq, Cyprus and Egypt. The habitat is varied and the climatic environment is Mediterranean on the coast and subtropical and dry inland.

Physical Characteristics

These animals are of medium size, with a narrow body and long, thin legs. The coat colour is light or reddish to dark brown, males being darker in colour than the females. The skin is medium in thickness and soft, while the hair is short and glossy. The head is long and narrow, the horns small and short, the hump is hardly noticeable, particularly in the female, and the dewlap is relatively well developed. The udder of the female is of medium size with long, thin teats. A description of the breed has been published by Brown (1964).

Utility

It is usually considered to be a milking breed with average production (Table 7.3). The breed was used as a source of foundation cattle in the Zionist settlements in Palestine in 1912 and was upgraded using Holstein (Hirsch & Shindler, 1957). It is said that this breed is particularly heat tolerant and that individuals are long-lived. Nevertheless, it faces extinction due to continuous crossbreeding with imported milking-type cattle. There are probably few purebreds left.

Gir (Fig. 7.8)

Synonyms: Decan, Kathiawari, Sorthi, Surti.

Related Types.

There is definite evidence of Gir blood in the Mewati, Deoni, Krishna Valley and Nimari breeds and blood-grouping data suggest that the Gir is also related to Red Sindhi, Sahiwal and Afghan cattle.

Origin and Habitat

The breed originated in the forest area of the Gir hills, Gujarat State, on the west coast of India where the climatic environment is of the monsoonal tropical type.

Physical Characteristics

These cattle are moderately large, heavy animals. The coat colour is characteristic and varies from yellowish red to black or white with dark red or chocolate-brown patches distributed all over the body. The skin is loose, pliable and fine and the hair short and glossy. They possess a very prominent and broad forehead and the ears are long and pendulous. The horns are moderate in size, curving away from the head in a downwards and backwards manner and then inclining a little upwards

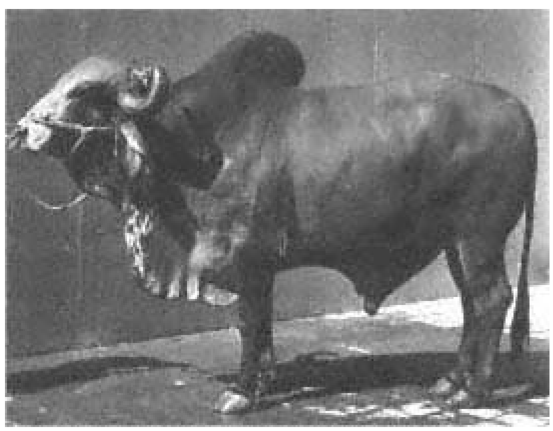

Fig. 7.8
Gir.

and forwards, taking a spiral inward sweep and finally ending in a fine taper. The hump is large. The dewlap is only moderately developed while the sheath in the male is large and pendulous.

Utility

They are fairly good milkers (Table 7.3) and are also used extensively for draught purposes. Although they are not slaughtered in India for beef, outside India they have an excellent reputation as beef animals and large numbers have been exported to Brazil from whence they have been introduced to other American countries. Gir are one of the foundation breeds of the American Brahman and the Indú-Brazil, and are also used as a pure breed in Brazil.

Hallikar (Fig. 7.9)

Origin and Habitat

This is one of the south Indian long-horned zebu breeds and is found mainly in the Tumkur, Hassan and Mysore districts of Karnataka State, India. The climatic environment in the area is montane tropical.

Physical Characteristics

These cattle are of medium size, compact and muscular in appearance, with strong legs. The differences between male

Fig. 7.9
Hallikar.

and female in size and build are not so well marked as in other breeds as the female has a muscular, masculine appearance. The coat colour is grey to dark grey with darker shadings on the fore and hindquarters. Frequently, there are light grey markings on the face, dewlap and under the body. The skin is fine and the coat short and glossy. The face is long, the forehead prominent and the ears small. The horns emerge close to each other from the top of the poll and are carried backwards for nearly half of their length, and then bend forwards inclining towards their tips which are black and sharp. The hump is moderately developed as is the dewlap. The sheath is very small and close to the body.

Utility

The Hallikar is one of the best all-round draught breeds to be found in southern India, but like other southern Indian cattle they are poor milkers (Table 7.3).

Hariana (Fig. 7.10)

Synonym: Haryana.

Related Types.

Hariana are somewhat similar to the Bhagnari, Gaolao and Ongole breeds; a closely related type being the Shahabadi, a breed found in West Bihar and Uttar Pradesh, India.

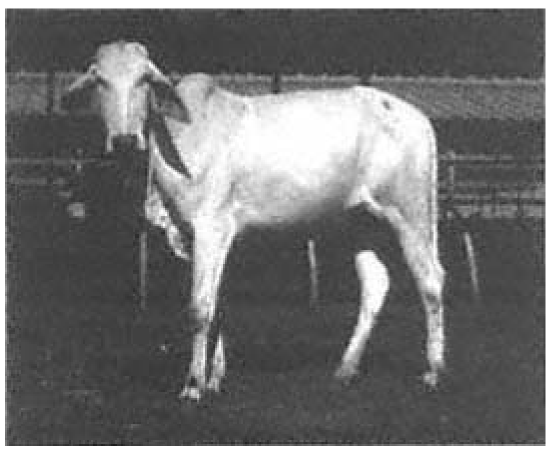

Fig. 7.10
Hariana.

Origin and Habitat

The breed originated in Haryana State, India, north of the tropic. These cattle are, however, bred throughout northern India and according to Bhat (1984) the breed is the most important in India. The climatic environment is subtropical and semi-arid, the mean annual rainfall being 450 mm.

Physical Characteristics

This is a compact animal of graceful appearance. The coat colour is white or grey, being darker over the hindquarters in the male. The skin is pigmented, fine, thin and tight. The face is long and narrow and there is a well-marked bony prominence at the centre of the poll. The ears are small and somewhat pendulous. The horns are fine and short, and thinner in the female than in the male. The hump is large and well developed in the male but of medium size in the female. The dewlap is moderately well developed but thin in the male; the sheath is short and tight. The navel flap is close to the body. The udder of the female is relatively large and extends well forward. The teats are of medium size, the fore being longer than the hind.

Utility

The cows milk moderately well (Table 7.3) and bullocks make powerful work animals. As the Hariana is of such importance in northern India a breeding programme has been developed to improve the breed as both a milk producer and a working animal (Nagarcenkar, 1983b; Bhat, 1984).

Kankrej (Fig. 7.11)

Synonyms: Bannai, Nagar, Sanchore, Talabda, Vadhiyar, Wadhiar, Wadial, Wagad, Wagadia.

Origin and Habitat

This breed originated in the Rann of Cutch, north Gujarat, India, where the climatic environment is tropical to subtropical and dry.

Physical Characteristics

This is a large animal. The coat colour varies from silver to iron-grey or steel-black. Newborn calves are coloured a rusty-red on the poll. The skin is pigmented and

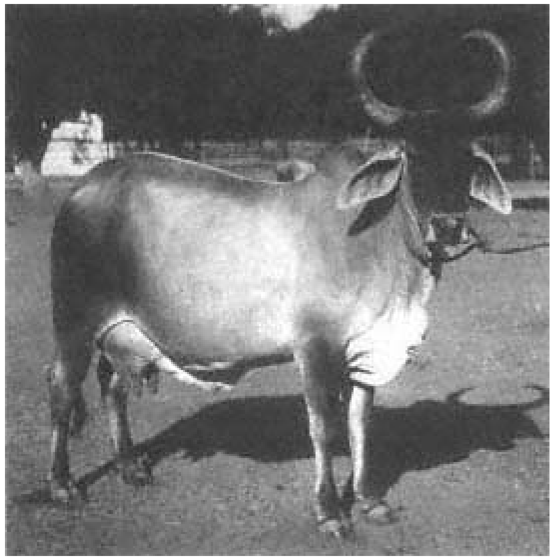

Fig. 7.11
Kankrej.

the hair is soft and short. The forehead is wide with prominent orbital arches. The ears are large and pendulous. The horns are large and lyre-shaped, and covered in skin to a much higher point than is normal in other breeds. The hump is well developed. The dewlap is thin and pendulous, the males possessing pendulous sheaths.

Utility

In India this is a dual-purpose milk and draught breed, but it has excellent potentiality for beef production and large numbers have been exported to Brazil where it has been used as one of the foundation breeds of the Indú-Brazil. Some Kankrej-type animals were also included in the foundation stock of the American Brahman. It is also used as a purebred in Brazil, where it is known as the Guzerá.

Ongole (Fig. 7.12)

Synonym: Nellore.

Related Types.

It has considerable conformational similarity with the Gaolao and Bhagnari breeds and blood group data suggest that it is also related to the Hariana.

Fig. 7.12
Ongole.

Origin and Habitat

The Ongole originates from the coastal plains of Andhra Pradesh State, India where the climate is tropical with a low to medium annual rainfall.

Physical Characteristics

These are large, long-bodied cattle with a short neck and long limbs. The normal coat colour is white, but the male has dark grey markings on the head, neck and hump and sometimes black points on the knees. Red or red and white animals are occasionally seen. The skin is of medium thickness and often shows black mottled markings. The head is long; the ears are moderately long and slightly drooping. The horns are short and stumpy, growing outwards and backwards, and are thick at the base. The hump in the males is well developed and erect. The dewlap is large and fleshy and hangs in folds that extend to the navel flap. The sheath is slightly pendulous.

Utility

They are primarily used for work, being usually very docile. The cows are fair milk producers (Table 7.3). An Ongole Cattle Improvement Society has been founded to preserve and improve the breed (Nath, 1985). Animals of this type have been exported to many countries and they have contributed genes to both the American Brahman and the Indú-Brazil breeds. Outside India, they are considered to be good beef animals for use under very adverse conditions. They are rapidly becoming one of the major beef breeds in Brazil. In Indonesia crossbreds of Ongole and local cattle have been selected to form a new breedthe Sumba Ongole.

Red Sindhi (Fig. 7.13)

Synonyms: Malir, Red Karachi, Sindhi.

Origin and Habitat

The original herd was founded at Malir, outside Karachi, in Pakistan and they may have been derived from hill-type cattle. They are somewhat similar to the Sahiwal and they may be related to the red Afghan cattle and also possess some Gir blood. The home base of the breed is now around Karachi, just outside the tropics, where the climatic environment is subtropical and semi-arid.

Physical Characteristics

The Red Sindhi is a medium to small animal with a deep, compact frame and round, drooping quarters. The coat colour is usually red, varying from dark red to dun yellow, often with specks of white on the dewlap and the forehead. In the male the colour is darker on the shoulders and thighs. The hair is soft and short; the skin is loose, of medium thickness and usually pigmented. The ears are of moderate to large size and drooping. The horns are thick at the base and emerge laterally, curving upwards. The hump is of medium size though well developed in the male. The dewlap and sheath are pendulous. The udder inclines to be pendulous and the teats unduly large.

Utility

It is considered one of the best dairy breeds in the Indian sub-continent (Table 7.3),

Fig. 7.13
Red Sindhi.

though it is also used for light work. It has been exported all over the tropical world and used for upgrading indigenous cattle, particularly for milk production.

Sahiwal (Fig. 7.14)

Synonyms: Lambi Bar, Lola, Montgomery, Multani, Teli.

Origin and Habitat.

This breed originated in the district of Montgomery in the West Punjab, Pakistan, and is related to the Afghan, Red Sindhi and Gir breeds. The climatic environment of the original habitat is subtropical and arid.

Physical Characteristics

It is a large, heavily built, long, deep, rather fleshy animal. The coat colour is varied, with reddish dun being rather common. Other coat colours are pale red, dark brown and almost black flecked with white. The skin is frequently unpigmented. The head is broad and massive in the male. The ears are of medium size with black hair on the fringes. The horns are very short and thick and loose horns are common in the female. The hump of the male is massive and frequently falls to one side. The dewlap is large and heavy, the navel flap loose and hanging; the sheath in the male is pendulous. The udder of the female is large and sometimes pendulous.

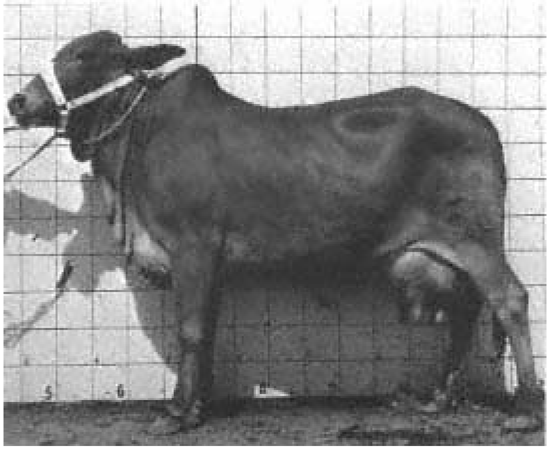

Fig. 7.14
Sahiwal.

Utility

This is one of the more productive tropical dairy breeds (Table 7.3) and cattle of this type have been exported to many parts of the tropical world. In Jamaica they have been crossed with the Jersey to provide the foundation stock for the breed known as the Jamaica Hope, and in East Africa they have been used widely for upgrading Small East African Zebu cattle. In Australia the Sahiwal has been used in the development of two new dairy breeds, the Australian Milking Zebu (AMZ) and the Australian Friesian Sahiwal (AFS). In both Australia and New Zealand a new export trade has been developed: that of crossbred (Sahiwal × European milking breeds) dairy heifers to Southeast Asia. In India a progeny testing programme involving some 750 cows has been organized (Nagarcenkar, 1983a). In Kenya a National Sahiwal Stud was established in 1962. Although the Sahiwal is basically a dairy breed, cattle of this type can be used for beef and work purposes.

Sunandini

Origin

This breed has been developed from crossbreds in Kerala State, India. Crossbreeding commenced in 1963 at Matupatti farm, located at an altitude of 1800 m in the western Ghats. Indigenous cows were crossed with imported Brown Swiss bulls. The resulting female halfbreds were back-crossed during 196667 to Brown Swiss bulls, to produce 3/4 bred Brown Swiss cattle. These were crossed with F1 half-breds to produce cattle that were 5/8 Brown Swiss × 3/8 Indigenous. The latter were then mated *inter se*, the bulls being subject to progeny testing. The resulting crossbreds (5/8 Brown Swiss × 3/8 Indigenous) were named Sunandini and recognized as a breed in 1979.

Utility

The Sunandini has been bred for milk production but the bullocks of this breed appear to be as good as indigenous bullocks for work purposes. There are now a very large number of cattle of the Sunandini type in Kerala and a combination of improved feeding and management of genetically improved milking cattle has led to a ten-fold increase in milk production within the state since 1970. Sunandini cattle have been exported to northeastern Sri Lanka.

Thai (Fig. 7.15)

Synonym: Siamese.

Related Types

There appear to be at least three types of indigenous cattle in Thailand. Those in the lowlands, those in the highlands and the fighting bulls of southern Thailand.

Origin and Habitat

Thai cattle are very similar in conformation to the other breeds of Southeast Asia. Little is known of their origin but it is likely that they are the result of crossbreeding between Zebu introduced by some route from the Indian sub-continent and humpless shorthorn-type cattle that possibly accompanied nomadic peoples coming from the north, and domesticated, indigenous *Bos (bibos)* spp. Fischer (1971) stated that Thai cattle are a variant of zebu cattle as they possess a karyotype ($2n = 60$) of which the Y-chromosome is acrocentric as in zebu cattle. Namikawa (1981), however, has shown that Thai cattle genes originate from *Bos taurus*, *Bos indicus* and *Bos (bibos)* spp. and that southern Thai cattle possess fewer zebu genes than northern Thai cattle. The climatic environment is varied; in the south of Thailand it is humid tropical, while in the northeast it is monsoonal and/or montane tropical.

Fig. 7.15
Thai fighting bulls.
(Courtesy of Indian Council of Agricultural Research, New Delhi.)

Physical Characteristics.

The cattle of the north are of medium size, hardy and relatively long-legged. The coat colour is usually yellow, red, brown or blacklighter shades being preferred by the local farmers. The head is short, the forehead narrow and the ears small. The horns are small, set well apart, curve upwards and slightly forwards and are pointed. The hump is cervico-thoracic, small in the male and virtually absent in the female. The dewlap is moderately large. Southern cattle are bulkier than the cattle in the north with short, strong legs and strong hooves. The coat colour is varied, but black, red and reddish grey are common, as is a speckled colour. The head is short or medium in size, as are the ears. The horns are similar to those of cattle in the northern provinces and are particularly well developed in the male. The latter possess a strongly developed cervico-thoracic and pointed hump, the female being more or less humpless. One particular characteristic of this breed is the very prominent sex organs in the male.

Utility

The majority of these cattle are used for draught purposes, but in south Thailand some are used for bull-fightinga local sport. Fighting bulls are selected at 4 years of age and should possess a good strong pair of horns and a well-developed chest, but they are not used until they are about 6 years of age. After being used for fighting they are maintained as draught animals or used for breeding purposes.

Tharparkar (Fig. 7.16)

Synonyms: Grey Sindhi, Thari, White Sindhi.

Related Types

A related type is the *Cutchi*, which originates from the Rann of Cutch, on the northwest border between India and Pakistan.

Origin and Habitat

The breed originated in the Thar desert in southwest Sind, Pakistan. This is an arid area where rainfall averages 200 mm per annum and in drought years cattle have had to be removed to the surrounding regions where they have interbred with Kankrej, Red Sindhi, Gir and Nagori cattle. The habitat is situated just outside the tropics.

Physical Characteristics

These are strongly built, medium-sized animals with comparatively short, straight limbs and good feet. The skin is pigmented and thin, the hair fine and short. The coat colour is usually white or grey with a light grey stripe along the top line. In the male the grey colour may deepen with age, particularly on the face and hindquarters. Black and red-coloured cattle are also seen. The head is medium in size, the forehead broad and flat; the ears are long, broad and semi-pendulous. The horns are set well apart and curve gradually upwards and outwards, ending in blunt points that are inclined inwards. The horns of the male are thicker, shorter and straighter than those of the female. The hump is moderately well developed and firm; the dewlap is of medium size; the sheath in the male is of moderate length and semi-pendulous and the navel flap in the female is prominent.

Utility

This is one of the best dual-purpose, workmilk breeds found in the Indian subcontinent. It will milk (Table 7.3) under very poor feeding conditions and has great powers of endurance and resistance to poor feeding and to drought conditions. Large numbers of these cattle have been exported, particularly to the

Fig. 7.16
Tharparkar.

Democratic Republic of Congo, Iraq, Sri Lanka and the Philippines.

African Breeds

Africander (Fig. 7.17)

Related Type.

Bolowanasynonym: Izankayi. These cattle have been upgraded with Africander and have now lost their identity as a separate type.

Origin and Habitat

It is generally recognized that this breed originated from the cattle owned by the Hottentots in the seventeenth and eighteenth centuries, but some Portuguese workers claim that it originated from an importation of cattle of the Alentejo breed from Portugal. The early Dutch settlers in South Africa acquired their first herd of Africander cattle from the Hottentots in 1652. The climatic environment of the habitat might be described as modified subtropical to tropical in the north and Mediterranean in Cape Province.

Physical Characteristics

Africanders are large, muscular and hardy. The coat colour is usually a shade of red, often with white marks on the underline. The hair is short and glossy; the skin thick, pliable and amber to yellow in colour. The

Fig. 7.17
Africander.

head is long; the ears small and pointed. The horns are long, wide and have a downwards and backwards sweep where they leave the head. The horns are oval in cross-section and have a characteristic twist. The male has short, strong horns, while those of the female are thinner and more spiral. The hump is cervico-thoracic and prominent in the male. The dewlap is large with loose folds and the umbilical fold is well developed.

Utility

These cattle were originally developed as draught animals and were considered exceptionally good for this purpose, but more recently they have been developed for beef production (Table 7.2). This is the main indigenous breed found on South African ranches and it is well adapted to the warmer regions provided that the climate is not too wet nor too dry. A breed society was founded in 1919 and the herdbook was closed in 1936. Large numbers of these cattle have been exported to other countries in Africa, to the United States, the Philippines and to Australia.

Angoni (Fig. 7.18)

These are the shorthorned zebu cattle found in Zambia, Malawi and Mozambique in an area

Fig. 7.18
Angoni.
(Courtesy of C. Walker.)

south and west of Lake Malawi. There are four types, but it is likely that they all have the same origin and that they are descendants of shorthorned zebu cattle that were introduced from the north.

Related Types

(1) *Zambia Angoni*.

(2) *Malawi Angoni*.

(3) *Mozambique Angoni*synonyms: Angone Zambesi, Angonia Zebu, Tete, Zulu.

(4) *Malawi Zebu*synonyms: Nyasa Shorthorned Zebu, Nyasa Zebu.

Origin and Habitat

These cattle represent the southernmost distribution of the shorthorned zebu cattle of East Africa. The habitat is very varied both climatically and topographically, but the climate is generally tropical and dry.

Physical Characteristics

Zambia Angoni are medium-sized, light-boned animals. The coat colour is very variable. The hair is short and the skin thin, loose and pigmented. The ears are of medium size. The horns are usually short and stout, but approximately 15% possess lyre-type horns. The hump and dewlap are well developed in both sexes. Horns of the Malawi Angoni are usually large, the hump is more variable while the dewlap is generally less developed than in the Zambia Angoni. Mozambique Angoni are smaller animals, their horns are short and stout and their humps are very well developed. The Malawi Zebu is also a small animal very similar to the Small East African Zebu in conformation.

Utility

These cattle are used for draught, milk, meat and ceremonial purposes. The Zambia Angoni appear to possess some beef characteristics and selection for these is taking place at local experimental stations. It has been stated, on the other hand, that the meat of the Mozambique Angoni is dry, coarse and tasteless.

Ankole (Fig. 7.19).

Synonyms: Ankole Longhorn, Toro, Wakuma.

Fig. 7.19
Ankole.

Related Types

(1) *Bahima*synonyms: Banioro, Bunyoro, Nsagalla.

(2) *Watusi*synonyms: Barundi, Kivu, Kuku, Nyambo, Watusi Longhorn.

(3) *Kigezi*.

(4) *Bashi*.

Origin and Habitat

These are sanga cattle with large or medium-sized, lyre-shaped horns and small humps, and the principal owners are two related Hamitic pastoral tribes known as the Bahima and the Watusi. These cattle are found in Uganda in two regions separated by a tsetse belt, in Rwanda, Burundi, in the Kivu district of the Democratic Republic of Congo and in northwestern Tanzania. The climatic environment is very varied, ranging from the hot dry climate of the Ruzizi valley to the cool upland areas of Rwanda.

Physical Characteristics

The Bahima are large, long-legged animals with a straight back. The prominent and favoured coat colour is deep red, but red and white also occur. The hair is short and the skin soft, pliable and pigmented. The distinguishing features are the horns: these are very long and large, curving gracefully outwards and upwards and finally inwards. There is a great deal of variation in the type of horn. Some of the cattle have a horn span of 185190 cm while others have shorter, thicker horns and 2% are polled. The total horn weight is often as much as 6.8 kg or 1.7% of the body weight, but according to Trail & Sacker (1966) there does not appear to be any significant difference in the growth rate of horned and dehorned cattle from birth to 2 or 3 years of age. The males sometimes have a slight cervico-thoracic hump, but there is usually no hump in the female. The most common coat colours in the Watusi are brown, fawn, red or black, and combinations of these colours with white. There is a very wide variation in the size and shape of the horn and horn growth is sometimes deliberately stimulated. In Rwanda the *Nyambo* or *Inyambo* strain has exceptionally long horns, up to 23 m between the points, and is held to be sacred. There is also a shorthorned strain known as the *Inkuku* or *Kuku* found in the mountains.

The Kigezi are smaller and finer-boned cattle, paler in colour than the Bahima and with smaller, more upright horns. The Bashi is also a smaller animal, the common coat colour being red, fawn, black or white or combinations of these. The horns are much shorter and the hump is hardly developed in the male and is absent in the female.

Utility

These cattle are used primarily for social purposes and for milk production, the Bashi type being the best milk animal (Table 7.3). They do not make particularly good beef cattle and are not normally used for work purposes. They are more susceptible to rinderpest than the Zebu, and in Uganda and Tanzania the total number of these cattle appears to be slowly declining as cattle owners replace them by crossbred zebu-type animals.

Boran (Fig. 7.20)

There are three types related to the Boran of Ethiopia:

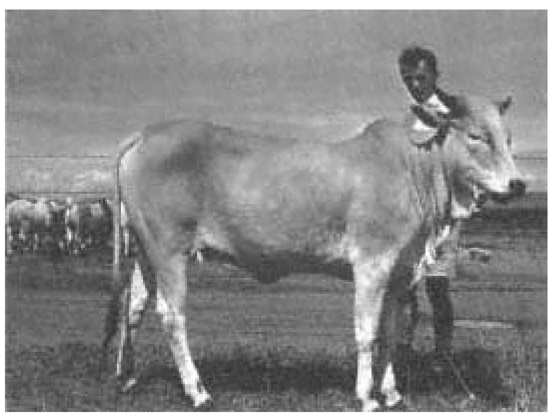

Fig. 7.20
Boran.

(1) *Somali Boran*synonym: Avai.

(2) *Tanaland* or *Orma Boran*synonym: Galla.

(3) *Kenya Boran*.

Origin and Habitat

Boran originated from southern Ethiopia (Alberro, 1986), but today the breed is found in southern Ethiopia, Somalia and Kenya. In Kenya the Boran has become an important beef breed. The type of Boran cattle now found on the ranches originated from animals sold to the European farmers by Somali traders, and there is no doubt that some of the herds include cattle that possess some temperate-type genes, particularly Hereford, as cattle of this breed were imported into Kenya during the first decades of the twentieth century and used as foundation stock on the ranches. They were later upgraded using Boran bulls. The original habitat was tropical and semi-arid, but in the major ranching areas it is montane, tropical and semi-arid.

Physical Characteristics

The Ethiopian Boran is a fairly large, long-legged animal with good body conformation. Some of the Tanaland Boran are inclined to legginess and are rather slab-sided. The coat colour of all types is normally white or grey, but red or pied colours occur. The Somali type is normally white with black points. The Tanaland Boran is also usually white, but shades of fawn occur. The Boran on the ranches in Kenya is typically white with black points, but fawn, red and black animals are seen and cattle in some of the herds are being bred for other colours apart from white. The Kenya Boran and the Somali Boran usually possess a pigmented skin, but the skin of the Tanaland Boran is not always pigmented. The skin of all types is thin, loose and pliable. The head is medium to long. The ears are small and not pendulous. The horns are usually small, thick at the base, pointed and directed forward. In the Tanaland and ranch types the horns are variable. Polled animals are not uncommon. The hump is well defined, upright and thoracic. It is sometimes folded on one side and is larger in the male than in the female. The dewlap and sheath are not excessively developed in the Somali Boran but more so in the Tanaland Boran. The improved Boran on Kenya ranches is characterized by a very straight top line and well-developed hindquarters.

Utility

These cattle are used by the semi-nomadic peoples primarily for milk, and if selected for milk production are moderately good milkers (Table 7.3). On the ranches they have been selected for beef purposes and now appear to be one of the outstanding beef breeds of Africa (Table 7.2). Unlike most Small East African Zebu, the Boran are susceptible to tick-borne diseases and particularly to East Coast fever (ECF). Because of their reported productive ability and their size, they are much in demand in the tick-infested areas and a considerable number of experiments have been made to attempt the pre-immunization of these cattle so that they can be used throughout East Africa. Some success had been claimed.

Mashona (Fig. 7.21).

Synonyms:

Amajanja, Ikomo eza Makalanga, Makalanga, Makaranga, Mombe, Ngombe, Ngombe Dza Maswina, Ngombe Dza Vakaranga.

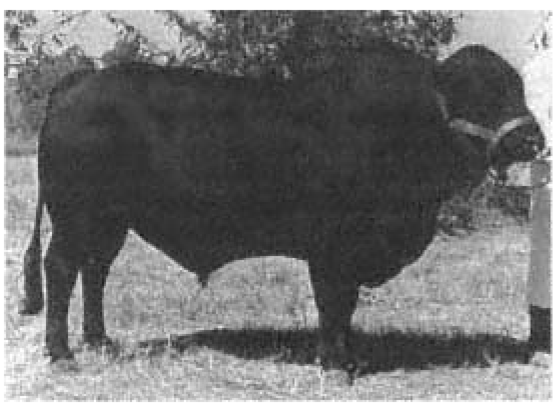

Fig. 7.21
Mashona.
(Courtesy of Commonwealth Bureau of Animal Breeding and Genetics.)

Origin and Habitat

These cattle are said to have arrived in the region with a people migrating from the north into Zimbabwe and they are now found over a wide area although they are named after the Shona people of Mashonaland, located in the eastern part of Zimbabwe. During the twentieth century they have been extensively crossed with temperate-type and Africander cattle on Zimbabwean ranches.

Physical Characteristics

The general conformation is compact, fine-boned and small. The most common coat colours are black, red, brown with yellow muzzle, brownish black with a lighter back stripe, dun, yellow, cream, black and white, red and white, and brindle, in that order. The hair is short and glossy; the skin well pigmented and of fine texture. The head is short and dished. The ears small and pointed. The horns tend to be of medium size, growing upwards and outwards, though polled animals are quite common. The hump is cervico-thoracic, moderate in size in the male and small in the female. The dewlap is small. The udder is small and is placed well forward and possesses small teats.

Utility

These are good beef and draught animals, being extremely docile and hardy. They are rarely milked and are not considered to be a milking breed. Some production data is provided in Tables 7.2 and 7.3.

Mpwapwa

Origin

This is a new breed, still under development at the Livestock Breeding Station, Mpwapwa, in the central region of Tanzania. In the 1930s and the 1940s Tanzania Shorthorn Zebu (TSZ) from several regions and Ankole from Bakoba were managed together with Boran from Kenya, Sahiwal and Red Sindhi from the Indian sub-continent and Ayrshire from the UK. In the 1950s and 1960s there was interbreeding and more recently additional Sahiwal and *Bos taurus* blood has been introduced into the breed. Since 1975 selection has been based on performance. According to Katyega (1988) the approximate composition of Mpwapwa cattle is 20% TSZ : 10% Boran : 5% Ankole : 35% Red Sindhi : 20% Sahiwal : 10% *Bos taurus* (mainly Ayrshire). Syrstad (1990) estimated that the characteristics of the Mpwapwa are derived 60% from Asian, 30% from African and 10% from European cattle.

Physical Characteristics

These are medium-sized, deep-bodied cattle. The coat colour is normally solid light to dark red but some animals possess mottled or speckled coats. The hump is quite large in the male, smaller in the female. The dewlap and sheath are moderate in size.

Utility

Selection is primarily for milk production in the harsh environment of central Tanzania. Average production of date has been approximately 1000 kg of 4.75% fat milk per lactation (Mchau, 1988). As there are only a few hundred animals in the Mpwapwa herd and 30004000 Mpwapwa-type cattle in the country, according to Katyega (1988), it is too soon to predict the future of the breed.

N'Dama (Fig. 7.22)

Synonyms: Boenca, Fouta Djallon, Fouta Jallon, Fouta Longhorn, Fouta Malinke, Futa, Gambian Longhorn, Mandingo.

Origin and Habitat.

This is a humpless breed of the Hamitic Longhorn type and the ancestors of this breed were probably the first domesticated

Fig. 7.22
N'Dama.

cattle in Africa. They are found today in Liberia, Guinea, Gambia, south Senegal, north Côte d'Ivoire, Sierra Leone, north Benin, Burkino Faso, Guinea Bissau and Mali. It is considered that the focal point in West Africa from which the breed spread is the Fouta Djallon plateau in Guinea. Approximately one-third of the total population of N'Dama cattle are to be found in the Republic of Guinea, where a centre for the selection, multiplication and improvement of the breed has been established (Devillard, 1984). The breed has apparently increased in number during the last 100 years and has acclimatized to life in or on the edges of the rainforest of West Africa. The northern limit of distribution of this breed approximates to the northern limit of the tsetse-infested area and to the southern limit of distribution of Zebu. The climatic environment of this area can generally be characterized as humid and tropical.

Physical Characteristics

It is a small, humpless, well-built animal with a straight top line and short, fine limbs. The coat is usually yellow, fawn, light red or dun in colour, although there are black and pied animals with black or fawn on a white background. The Sierra Leone variety is usually coloured various shades of red. The skin is pigmented, the colour varying from black to light brown, and the hair is soft and short. The head is short and broad, the ears small and horizontal. The horns are lyre-shaped and grow sideways and then forwards and upwards from the poll. In mature cattle they are 4550 cm long, circular in cross-section and white with dark tips. Polled cattle are not uncommon. The dewlap and umbilical fold are not large. The udder of the female is very small and set high between the legs.

Utility

They are poor milkers (Table 7.3), but they can be, and sometimes are, used for draught purposes. They are essentially beef animals producing reasonably good carcases under poor grazing conditions (Table 7.2). Their meat is of good quality. Their most unusual attribute is that they are inherently tolerant to trypanosomosis and that this tolerance appears to be enhanced by exposure to infection but breaks down under stress. Their trypanotolerance has been studied in detail (ILCA/FAO/UNEP, 1979). They are also said to be tolerant of piroplasmosis and they have a reputation for longevity.

On account of their tolerance to trypanosomosis, cattle of this breed have been imported into Ghana, Nigeria and the Democratic Republic of Congo. Fertilized N'Dama embryos have been successfully introduced into East Africa using an embryo transfer technique (Jordt *et al*., 1986). In the nineteenth century they were exported to the West Indies where they were crossed with the Red Poll to form the breed known as the Nelthropp.

Small East African Zebu (Fig. 7.23)

Synonym: East African Shorthorned Zebu.

These are the major type of cattle found in most parts of East Africa, with different names in different regions. The main related types are:

(1) *Mongalla*synonyms: Latuka, Southeastern Hill Zebu, Southern Sudan Hill Zebu.

(2) *Lugware*synonyms: Bahu, Lagware and Lugwaret.

(3) *Bukedi*synonyms: Eastern Province Zebu, Lango, Nkedi, Teso, Uganda Zebu.

(4) *Nandi*synonyms: Akamba, Kamba, Kavirondo, Kikuyu, Ukamba, Wakamba.

(5) *Masai*synonym: Maasai.

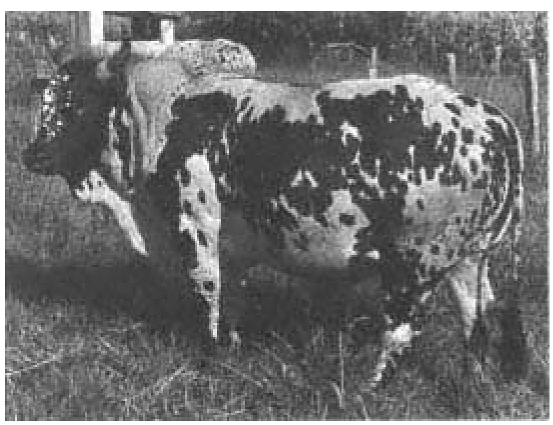

Fig. 7.23
Small East African Zebu.

(6) *Tanzania Zebu*synonyms: Chagga, Iringa Red, Masai Grey, Mbulu, Mkalama Dun, Singida White, Wachagga.

(7) *Zanzibar Zebu*.

Origin and Habitat

Although there are so many different types of Small East African Zebu, varying somewhat in size and colour, it is generally accepted that they all have a common origin. Undoubtedly, the total number of these cattle has increased during the twentieth century and it is likely that they are now used in areas where sanga cattle were previously maintained. The climatic environment of the habitat is very varied and they are managed from sea level to 2740 m, but generally they are most numerous in the wetter and more humid areas of East Africa, whereas the larger Zebu, such as the Boran, are more numerous in the drier areas.

Physical Characteristics

The majority are small, stocky animals. Coat colour varies over a very wide range from white to black. Their hair is short and soft and their skin pliable and deeply pigmented. The head is of medium length. Horn shape varies over a wide range; in general, horns are short, grow outwards and curve slightly inwards at the tip. Humps are pronounced in both sexes, but are larger in the male than in the female. In the male they often fall over backwards or to one side. Dewlaps vary in size but tend to be small, as are the umbilical folds.

Utility

Some types of this breed are excellent milkers for their size, particularly the Bukedi and Nandi (Table 7.3). They are all used, however, for draught, milk and meat production and occasionally for ceremonial purposes. Animals that are owned by the semi-nomadic peoples, such as the Masai, are also used for the production of blood which is a minor part of the staple diet. In general, these cattle are more tolerant of tick-borne disease than the larger types of Zebu.

Sokoto (Fig. 7.24)

Synonyms: Gudali, Sokoto Gudali.

Origin and Habitat

These cattle are typical of the shorthorned Zebu found in West Africa. In general appearance and conformation they are somewhat similar to the grey-white breeds of Indian cattle. This particular breed is found in Sokoto Province of northwestern Nigeria where the climatic environment is semi-arid and tropical.

Physical Characteristics.

They are medium-sized, deep-bodied animals. The usual coat colour is white or cream in the female and light grey or cream with dark shading over the poll, neck, shoulders and tail in the male. There are some males that are coloured dun with blue-grey shading. The hair is short and the skin medium thick, loose and pigmented. They possess pendulous ears. The male has very short, lateral upturned

Fig. 7.24
Sokoto.

horns while the female has smaller but slightly longer horns. The hump is almost cervico-thoracic and well developed in both sexes. A well-pronounced dewlap and umbilical fold is possessed by both sexes.

Utility

This is essentially a dairy/draught breed, but these cattle are also used for beef production. It is a fair milker under natural grazing conditions (Table 7.3) and as a work animal it is slow, docile, sturdy and reliable.

Sudanese (Fig. 7.25)

Synonyms: Arab, Northern Sudan Shorthorned Zebu, North Sudan Zebu.

Origin and Habitat

There are a number of related types, the major ones being the following:

(1) *Kenana*synonyms: Blue Nile, Fung, Rufa'ai.

(2) *Butana*synonyms: Bambana, Batahin, Hodendowa, Red Butana, Shukria.

(3) *White Nile*.

(4) *Baggara*synonyms: Darfur, Kordofan, Kordofani, Western. These cattle are of very mixed origin.

(5) *Northern Province*synonyms: Deleigabi, Dongola, Geigarawi, Shendi.

In general it is difficult to specify distinct types as over wide areas there has been a mixture of these

Fig. 7.25
Sudanese.

related animals, some of whom closely resemble the Indian-type Zebu in conformation. Of the related types, the Kenana and White Nile are representative of the nomadic cattle of the northern Sudan, their habitat being semi-arid desert scrub where the rainfall is 350450 mm. The Northern Province type of cattle come from the riverine region between Khartoum and the Egyptian border and are of somewhat mixed origin, while the Butana are found in the semi-arid area between the Blue Nile and the river Atbara. Baggara cattle have been derived from stock originally introduced from countries further to the west and mixed with many other types. They are found in the savanna regions between the Nile and the western frontier of the Sudan.

Physical Characteristics

The different types vary in size, but much of this variation may be due to environmental influences. The coat colour is also variable, possibly due to past selection by man. White-grey predominates in the Kenana. In the White Nile there are many colours: red, fawn, white, black and admixtures of these. In the Butana and in the Northern Province cattle the coat is usually red although mixed-colour animals are found. In the Baggara the most usual coat colour is white with red and, less often, black markings, but cattle of many different colours are seen. Kenana calves are born with a red-brown coat that changes to white-grey at 3 to 6 months of age. The coat of the majority of these cattle is short and the skin loose. The horns seldom exceed 3135 cm in length, are shorter in the male than in the female, are oval in cross-section and grow from a flat poll in an outward and upward direction. There appear to be a few true polls although loose, hanging horns and scurs are common. The hump is cervico-thoracic to thoracic in position and slopes from front to rear. In Baggara cattle the hump in males is almost always cervico-thoracic and that of females is often very small. The dewlap is large and prominent, indeed in some cattle it is often double folded under the chin and may be continuous with the umbilical fold.

Utility

The majority of these cattle are kept by nomadic or semi-nomadic peoples and they are primarily used for milk production (Table 7.3), although surplus males are sold for slaughter. These cattle have a very strong herding instinct, are very docile and are well adapted for living in semi-arid areas. Within Sudanese breeds, the Kenana are considered the best milkers. Northern Province cattle are also used for work purposes. In a small number of Kenana herds the cattle have been especially selected for milk production and the results suggest that this breed is one of the most productive milk breeds in Africa.

West African Shorthorn (Fig. 7.26)

Two sub-groups may be distinguished (ILCA/FAO/UNEP, 1979). Larger animals found in the savanna and dwarf animals from the coastal and forest regions. There is some confusion in the nomenclature of these cattle but the larger type found in the savanna and known as the Savanna West African Shorthorn includes: Bakosi (syn. *Doayo, Namchi* and *Kapsiki*) an endangered breed from Cameroun; *Baoulé* from the Côte d'Ivoire and the *Lobi* from the Gaoua region of Burkina Faso that appear to be indentical types; the *Ghana Shorthorn*; the *Muturu*, found in the savanna regions of Benue and elsewhere in Nigeria and said to be an endangered species (Ngere, 1990); and the *Sombo* of northern Togo and Benin. The smaller or dwarf types found in coastal and forest regions include: the *Bakwiri* (syn. *Kosi, Muturu*) of the highland forests in Cameroun; the *Forest Muturu* (syn. *Nigerian Dwarf, Nigerian Shorthorn, Pagan*); the *Gambian Dwarf*; the *Lagune* of the coastal regions of the Côte d'Ivoire, Togo and Benin, said by Adeniji (1985) to be an endangered species; the *Liberian Dwarf*; and the *Manjaco* of Guinea Bissau.

Origin and Habitat

Today they are found in coastal forest and savanna areas between Gambia and the Republic of Cameroun and to a more limited extent in the interior. The climate of their habitat is mainly humid and tropical, but they are also found in some drier areas such as coastal Togoland, Ghana and Benin where the rainfall is

Fig. 7.26
West African Shorthorn.

comparatively low, and the interior savannas of Ghana, Côte d'Ivoire, Togo, and Burkina Faso.

Physical Characteristics

They are small, thickset animals with short, fine-boned limbs. The dwarf type is smaller than the savanna type. The skin is tight and pigmented and the coat usually black, dark brown or pied in colour. The head is short and broad, the animal possessing a broad poll and short horns that grow sideways and upwards and curve forwards at the extremities. In cross-section the horns are circular in the male and oval in the female. Polled animals are common. There is little dewlap or sheath.

Utility.

These cattle are poor milkers (Table 7.3), but they possess a reasonably good conformation and produce fairly good beef. They can be used for work purposes, but their capacity is small and their stamina limited. Like the N'Dama they also exhibit tolerance to trypanosomosis, but this tolerance is not as marked as that of the N'Dama and it can more easily be broken down if they are weakened by disease or malnutrition or if they are overworked. They have been introduced into the Central African Republic, Gabon, Congo and the Democratic Republic of Congo (former Zaire).

White Fulani (Fig. 7.27)

Synonyms: Akou (Cameroun), Bunaji, White Bororo, White Kano, Yakanaji.

Origin and Habitat

This breed is typical of the West African lyre-horned Zebu owned by the Fulani people. It is found in northern Nigeria and in the Cameroun in a climatic environment that is tropical and semi-arid. A related type is the Wodobe which appears to be intermediate in characteristics between the White Fulani and the Red Bororo.

Fig. 7.27
White Fulani.

Physical Characteristics

They are large animals. The coat is usually white with black points, but a few animals possess coats that are black with blue flecking or red and white. The skin is loose and pigmented and the hair soft. The ears are erect. The horns are medium to long, lyre-shaped and curve outwards and upwards. In some animals there is an outward turn again at the tip. The hump is well developed and often more or less cervico-thoracic in position. The dewlap is large and well developed, possessing many folds. The sheath and navel flap are not large. The udder of the female is well developed with medium-sized teats.

Utility

It is a triple-purpose breed, used primarily for milk production (Table 7.3) as milk constitutes the basic diet of the Fulani. These cattle fatten well on natural grasslands and they are good beef animals, possessing a light skeleton. They are good but slow workers. At Shika in northern Nigeria White Fulani have been crossed with the Holstein in an effort to produce a more productive milk animal for use in the region.

American Breeds

Brahman (Fig. 7.28)

Synonym: American Brahman.

Fig. 7.28
Brahman.

Related Type

Red Brahman. The only difference between these and other Brahmans is that they possess a red coat.

Origin and Habitat

The breed was developed in the Gulf area of the southwestern United States between 1854 and 1926. It is a Zebu derived from strains of the Kankrej, Ongole, Gir, Krishna Valley, Hariana and Bhagnari breeds, but as the former Mr Edgar Hudgins, a prominent Brahman breeder once stated, 'the truth of the Brahman breeding will never be known'. The foundation Zebu were either imported directly into the United States or indirectly through Brazil and Mexico.

The climatic environment of the Gulf coast where the Brahman breed was originally developed could be described as humid and subtropical, but cattle of this breed are now managed in many regions of the tropical and subtropical world.

Physical Characteristics.

As might be expected, the breed exhibits some variability in physical characteristics. It is a large animal with a long body of moderate depth, with long to medium-length legs and a straight back. The colour of the coat is normally a very light grey, but it may be red or black. The mature male is usually darker in colour than the female, with darker areas on the neck, shoulders, lower thighs and flanks. Calves often possess a red coat at birth that quickly turns grey. The skin is loose, soft and pliable, of medium thickness and is usually pigmented. The head is normally long. The ears are pendulous. The horns thinner than those of the female. The hump is large in the male, smaller in the female. The dewlap is large, but the sheath and navel flaps are not very pendulous. The udder in the female is of moderate size, as are the teats.

Utility

The Brahman is essentially a beef animal that grows well on poor, dry grazings (Table 7.2) and also responds to feedlot management. In the United States, Latin America and Australia it has been widely used for crossbreeding purposes, to produce Zebu × temperate-type beef animals that are well acclimatized to the tropical or subtropical environment and exhibit hybrid vigour. When the Brahman is continuously handled it is a docile animal, but if it is gathered only occasionally it can be very wild. It appears to have a long productive life, is not unduly troubled by ticks, biting flies, and mosquitoes, exhibits considerable tolerance to pink-eye and cancer-eye and is gregarious and a close herder, not responding well to hand mating. The American Brahman Breeders' Association was organized in 1924 and Brahmans have been exported all over the world, in particular to countries in the Caribbean, Central and South America, and to Australia, the Pacific islands and the Philippines.

Criollo Cattle

Criollo cattle are descendants of the first cattle to be introduced into the Americas from the Iberian peninsula. They were the major cattle population in the Americas at the beginning of the nineteenth century, being bred and herded from Oregon on the west coast and Florida on the east coast of North America, through the Caribbean islands and Central America, to Argentina in the south of South America.

The most useful attribute of the Criollo was that it appeared to be able to adapt itself to the myriad sub-climates of the Americas. Consequently there were many different Criollo sub-breeds or types. Unfortunately, the majority have been replaced by British and European dairy and beef breeds or by Zebu breeds or crossbreds. Today only a few purebred Criollo herds remain, the majority in Central America and Colombia (Rouse, 1977), and the continued existence of many of these herds depends upon universities, government departments or isolated breeders.

Some of the more important types and/or breeds of Criollo cattle are:

(1) *Argentine Criollo*a type that almost disappeared but that is now growing in number.

(2) *Bolivian Criollo*of which there are five distinct sub-breeds (J.V. Wilkins, 1995 pers. comm.).

(3) *Ecuador Criollo*described by Wilkins (1984).

(4) *Vallecaucano, Chino Santandereano, San Martinero, Blanco Orejinegro, Costeño con Cuernos* and *Romosinuano* breeds in Colombia.

(5) *Llanero* in the llanos of Venezuela.

(6) Milking Criollo types: in Costa Rica (*Tropical Dairy Criollo*), Venezuela (*Limonero*), Mexico (*Mexican Dairy Criollo*), Dominican Republic (*Dominican Milking Criollo*) and Guatemala (*Barrosa*).

(7) *Cuban Criollo* milking cattle described by Prada (1979).

As it is not possible to describe and discuss all the Criollo breeds and types listed above, one, the Romosinuano is described below.

Romosinuano (Fig. 7.29)

Synonyms: Coastal Polled, Morano-Sinuano, Polled Sinú.

Origin and Habitat

This is a Criollo breed found in north Colombia around the Sinú river and in the province of Bolivar. These cattle are believed to have originated from crossbreeding between Red Poll and/or Aberdeen Angus and Horned Sinú at the end of the nineteenth century. The habitat is either swampy or slightly undulating. The climatic environment is humid

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and tropical, the annual rainfall usually exceeding 1800 mm.

Physical Characteristics

The Romosinuano is a beef-type animal. The coat colour is red. The skin colour is deeply pigmented. The hair is scanty and short and many older animals possess a top line and rump completely devoid of hair. The breed is polled but scurs occur.

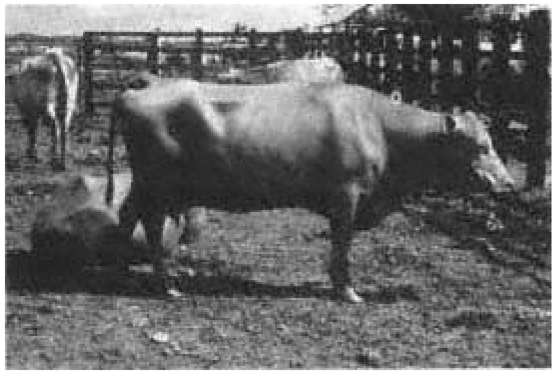

Fig. 7.29
Romosinuano.
(Courtesy of *Revista dos Criadores*.)

Utility

It is a beef breed (Table 7.2) that possesses a tendency to lay down gobs of fat, a characteristic of the meat that is now considered objectionable. Romosinuano are very docile animals and are easily herded.

Florida Cracker (Fig. 7.30)

Synonyms: Florida Native, Florida Scrub.

Origin

Cattle were first introduced into Florida by Ponce de León on his second voyage in 1521 (Arnade, 1961). These cattle were from the West Indies and of Spanish origin. Intermittent introduction of Spanish-type cattle followed throughout the sixteenth and seventeenth centuries, so that *c*. 1700 there were cattle ranches in Apalache (Caribbean coastal area), Gainesville (central Florida) and Palatka (St John's river, Atlantic coast), together with isolated herds scattered elsewhere (Arnade, 1961). Somewhat similar cattle introductions were also made into the southern regions of Georgia, Alabama and Mississippi. In the eighteenth and nineteenth centuries English-speaking settlers introduced

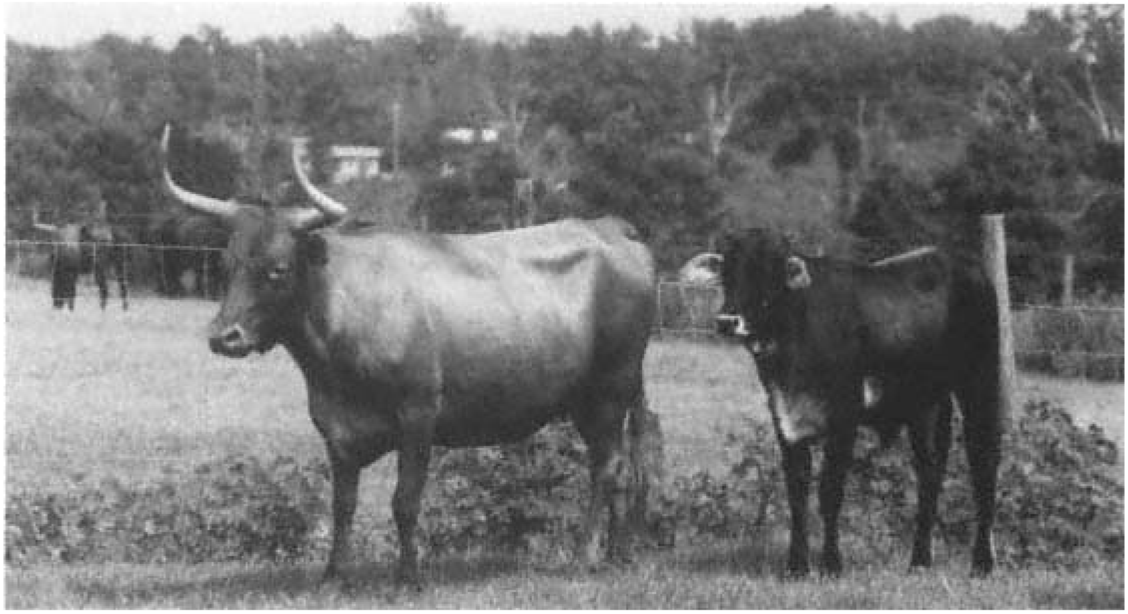

Fig. 7.30
Florida Cracker.

cattle into Florida from Georgia and the Carolinas and these are likely to have been of a non-descript shorthorn type. In the early part of the twentieth century English-type breeds, and in particular shorthorns, were introduced followed by Brahman and part-Brahman bulls in the 1930s (Olson, 1987).

The Florida Cracker had almost disappeared by the 1960s, but at this time interest in the breed revived. At present there are about 300+ purebreds maintained in four herds at state institutions (Lake Kissimmee, Payne's Prairie and Withlacoochee State Parks and the Florida Department of Agriculture in Tallahassee) and in a number of private herds. A Florida Cracker Cattle Breeders' Association was formed in 1988, a breed registry is being established and it is anticipated that there will be an increase in numbers of the breed.

Physical Characteristics.

These are small- to medium-sized cattle; mature cows weigh 280360 kg. They are varied in colour but red, black and dark brown are predominant, while white spotting and/or speckling is also common. The horns are smaller than those of the Longhorn and tend to turn upwards rather than outwards. The polled condition is known.

Utility

The Florida Cracker is a very hardy breed, well acclimatized to internal and external parasites, high temperatures and humidities and low quality forage. It is expected that it will be used to introduce, by crossbreeding, acclimatization characteristics into more productive beef-type breeds. It is representative of the cattle that were first introduced to the Americas by the Spanish.

Indo-Brazilian (Fig. 7.31)

Synonyms: Induberaba, Indú-Brazil.

Origin and Habitat

This breed originated in Minas Gerais State from crossbreeding between Indian breeds imported into Brazil; mainly Gir, Kankrej and Ongole cattle.

The habitat is varied and the climatic environment tropical.

Fig. 7.31
Indo-Brazilian.

Physical Characteristics

It is somewhat similar to the American Brahman, demonstrating characteristics from the foundation breeds.

Utility

It is a beef breed and some of the best herds are now found in the states of Minas Gerais and Bahia in Brazil.

Jamaica Hope (Fig. 7.32)

Synonyms: Jersey Zebu, Montgomery-Jersey.

Origin and Habitat

The breed has been developed from a herd founded at Hope, near Kingston, in Jamaica, in 1910. The farm was originally stocked with Creole (Criollo) and imported grade temperate-type cattle originating from Canada and the United Kingdom. In 1912 two Sahiwal bulls were imported from the Pusa herd in India and one was used for crossbreeding purposes. With the facilities available it was impossible to test all the different types of crossbreds produced so that the Ayrshire, Brown Swiss, Red Poll, Guernsey and Holstein crossbreds were discarded, leaving only the Jersey crossbreds. It is estimated that present-day Jamaica Hope cattle have inherited 7075% of their genes from the Jersey, 20% from the Sahiwal and a small percentage from Creole cattle.

In 1952 the herd was 'closed' and the Jamaica Hope was established as a new breed, a society being formed in 1953.

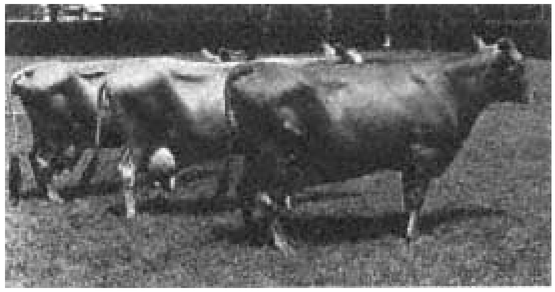

Fig. 7.32
Jamaica Hope.

The climatic environment is tropical and humid.

Physical Characteristics

The breed is very similar to the Jersey in conformation although these cattle are usually larger. There is no definite coat colour, it varies from fawn, brown and grey to black.

Utility.

The breed has been developed for dairying under humid tropical conditions and it is undoubtedly one of the most productive dairy breeds (Table 7.3) found in the tropics today with individual cows producing up to 9000 kg of milk per lactation. Reproductive efficiency is said to be good. Cattle of this breed have been exported to other Caribbean and to some Central and South American countries.

Jamaica Red Poll (Fig. 7.33)

Synonyms: Good Hope Red, Jamaica Red.

Origin and Habitat

The breed has been developed by the upgrading of indigenous Creole (Criollo) and Zebu crossbreds using Red Poll bulls. A Jamaica Red Poll Cattle Breeders' Society was founded in 1952 and the herdbook was closed in 1960. The habitat is varied and the climatic environment is tropical and generally humid.

Physical Characteristics

It is a large animal with a good depth of body and medium-sized legs. The coat colour should be dark to medium red; the hair sleek and dense; the skin fine; and the animal should be polled.

Fig. 7.33

Jamaica Red Poll.

Utility

The breed had been developed to produce beef at an early age off pasture and it is particularly well adapted to a humid tropical environment. Cattle of this breed have been exported to Latin American countries and the breed appears to be flourishing, particularly in Venezuela.

Nelore

Origin

The breed has been developed primarily from Ongole cattle, imported into Brazil from India between 1868 and 1962 (Santiago, 1967). There are two closely related types, the *Polled Nelore* and the *Red Nelore*.

Physical Characteristics

Nelore have a better beef conformation than the Indian Ongole. They are somewhat smaller when mature than the Guzerá and the Indo-Brazilian.

Utility

This is primarily a beef breed, characterized by high fertility and low calf mortality under extensive managerial conditions. It is rapidly becoming the most important cattle breed in Brazil, expanding in number faster than the Indú-Brazilian. Nelore cows have been crossed with Charolais bulls to form the *Canchim* breed.

Santa Gertrudis (Fig. 7.34).

Origin and Habitat

The Santa Gertrudis is a crossbred, 3/8 Zebu × 5/8 Shorthorn developed on the King Ranch in Texas. The breeding work undertaken in the evolution of the Santa Gertrudis is perhaps one of the more interesting examples of constructive animal breeding of the twentieth century. The King Ranch was originally stocked with Texas Longhorns and these were upgraded using Shorthorn and Hereford bulls. In 1910 the first crossbred Zebu were purchased by the ranch and between this date and

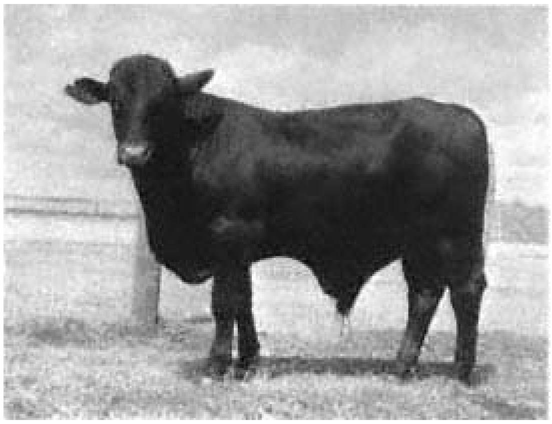

Fig. 7.34
Santa Gertrudis.

1940, by means of a well-planned breeding policy, the Santa Gertrudis breed was developed.

The original habitat is subtropical and semiarid, but the breed has now been exported to many different regions of the tropical and subtropical world.

Physical Characteristics

It is a large symmetrical, deep-bodied, strong boned animal. The coat colour should be a solid cherry-red, the hair short and straight and the skin thin, loose and pigmented red. The head is broad and the animal has a slightly convex forehead. The ears are medium to large and drooping. The horns are usually of the Shorthorn type and polled animals exist. The hump is of medium size in the male but absent in the female. The dewlap is well developed. The sheath and navel flap are of medium size. The udder of the female is of medium size with well-placed teats.

Utility

This is a beef breed that is said to have cold- as well as heat-tolerance characteristics and to be resistant to ticks. Some details of growth are provided in Table 7.2. Exports of cattle of this type have made a considerable impact on the beef industries in countries in the Caribbean,

Fig. 7.35
Australian Milking Zebu.
(Courtesy of Department of Primary Industries, Queensland.)

Central and South America and in Australia. Some doubts have been expressed as to the fertility of the breed in some tropical environments.

Australian Breeds

Australian Milking Zebu (Fig. 7.35)

Origin and Habitat

This breed is a recent zebu crossbred type. It has been developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) at the F.D. McMaster Field Station, Badgery's Creek from Sahiwal and Red Sindhi cattle imported from Pakistan and Australian Jerseys. A detailed account of the development of the breed has been published by Hayman (1974). The Australian Milking Zebu Society was formed in 1970. The climatic environment of the area in which they are used varies from warm temperate to tropical.

Physical Characteristics

Females are somewhat similar in appearance to Jerseys but are larger. The predominant coat colour is a golden to reddish brown. The bulls possess a cervico-thoracic hump.

Utility

This is a dairy breed with a good milk production (Table 7.3) but it also produces very acceptable beef carcases. They are more resistant to ticks than British cattle and possess good foraging abilities. Progeny-tested sires are available.

Droughtmaster (Fig. 7.36).

Origin and Habitat

These are crossbred cattle with 3/8 to 5/8 Zebu blood, mainly derived from red American Brahman cattle imported from Texas. There is also some infusion of Santa Gertrudis blood. The temperate-type inheritance has been derived from the Devon, Shorthorn, Hereford and Red Poll breeds, together with some genes from the Shorthorn inheritance in the Santa Gertrudis. A Droughtmaster Stud Breeders' Society was formed in 1962.

The climatic environment of the region in which they are utilized varies from humid tropi-

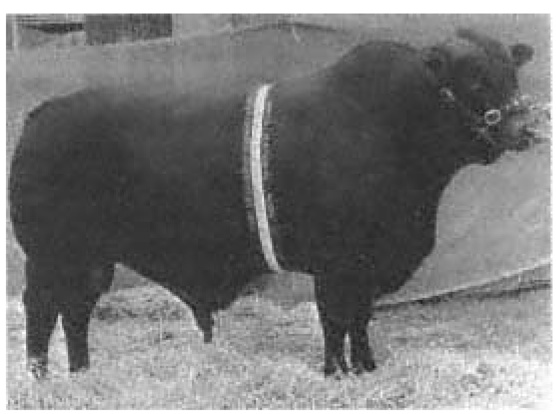

Fig. 7.36
Droughtmaster.

cal on the coast to semi-arid tropical and subtropical in the interior of the continent.

Physical Characteristics

These cattle are large, long-bodied and well fleshed. The coat is short and sleek and the skin loose and pliable. The coat colour is light or dark red. There are both horned and polled individuals. The dewlap and sheath in the male and the navel flap in the female are moderately developed. The udder of the female is of moderate size, possessing evenly placed teats.

Utility

This is a beef breed producing excellent-quality meat. Animals of this breed are resistant to tick infestation and appear to be more tolerant to babesiosis than the British breeds. Droughtmaster cattle have been exported to New Guinea and the Solomon Islands.

Production Systems in the Tropics

Many suggestions have been made for the classification of livestock production systems. These include proposals by Dittmar (1954), de Boer (1976) in Asia, Payne (1976) for beef producing systems, Ruthenberg (1980), de Boer (1977) for the International Livestock Centre for Africa (ILCA), Jahnke (1977) and Wilson (1995).

In the opinion of the authors none of these classifications provide a completly suitable framework for the evaluation of tropical cattle production systems on a worldwide basis. Either the criteria used are regional in concept and scope or the classification is too complex. For worldwide evaluation purposes a classification must be simple and be based on universally recognized criteria. The following classification is proposed.

I Extensive systems

A *Subsistence and/or semi-subsistence*

- Pastoralism
- Crop agriculture with extensive cattle production

B *Commercial*

- Ranching

II Semi-intensive systems

A *Semi-subsistence and/or semi-commercial*

- Sedentary crop agriculture with cattle production

III Intensive systems

B *Commercial*

- Rotational cattleforage crop production (ley farming)
- Integrated cattleperennial crop production
- Modern sector cattle production

The primary criterion used is the spacial characteristic of the production system; extensive, semi-intensive or intensive. Although the demarcation lines between these are in no way absolute and are, to some degree, dynamic and continuously changing, as for example, ranching systems becoming more intensive, they are sufficiently well identified with specific environments, economic systems and cultures to justify the divisions proposed.

The secondary criterion is the economic objective of the cattle owners. These may be either of a subsistence, semi-subsistence, semi-commercial or entirely commercial nature. The difference between a semi-subsistence and semi-commercial economic objective is obviously arbitrary, but for the purposes of classification it is assumed, as did de Boer (1977), that less than 50% of the total production of semi-subsistence producers is sold for cash whilst semi-commercial producers sell more than 50% of their total production. These economic objective demarcation lines are also continuously changing as subsistence cattle owners enter the market system and semi-subsistence cattle owners begin to specialize in response to market forces. An added complication is that most commercial producers specialize, managing only cattle, whilst subsistence, semi-subsistence and semi-commercial producers may utilize several types of domestic livestock, depending upon their economiccultural system and the environment in which they operate. Despite these problems it is considered that the different economic objectives create such distinct cattle management systems as to justify the divisions proposed.

Although the classification may not be completely satisfactory as a model or entirely logical in concept, the authors consider that it does provide a basis for a worldwide evaluation of tropical cattle production systems.

Details of the present geographical distribution of tropical cattle have been provided in Table 7.1. Guesstimates can be made of distribution by major managerial systems. These have been made using FAO cattle population information, statistical data from the major tropical countries relating to the internal distribution of cattle, personal knowledge and other relevant data. Using these criteria the approximate distribution of cattle by managerial system as a percentage of the total number of tropical cattle is as shown in Table 7.4.

Although these guesstimates should only be considered as an approximate guide, they do indicate the continuing important role of pastoral and ranching systems in tropical cattle production and that at least half of all tropical cattle are utilized in sedentary crop agricultural systems. Some 30% of cattle are managed in commercial systems, but only 5% in intensive commercial systems. It should also be noted that the situation is dynamic, with continuous and possibly accelerating change. In general the number of cattle managed within pastoral systems is declining, in some regions quite rapidly, whilst the number in semi-intensive and intensive systems is increasing.

Table 7.4 Approximate distribution of cattle by managerial system.

Managerial system	As % total number of tropical cattle
Extensive systems	
• Pastoralism	12.0
• Crop agriculture with extensive cattle production	7.0
• Ranching	25.0
Total extensive systems	44.0
Semi-intensive systems	
• Sedentary crop agriculture with cattle production	51.0
Intensive systems	
• Ley farming	0.5
• Integrated cattle/perennial crop production	1.3
• Modern sector	3.2
Total intensive systems	5.0

Extensive Systems

Pastoralism

Pastoralism is difficult to define as a livestock system, as there is a continuum between pastoral nomadism, in which livestock-owning people practise no settled agriculture and sedentary cultivation in which people practise livestock raising. In a very simplified form this situation is shown diagrammatically in Fig. 7.37.

As a consequence pastoral societies are usually very complex, though on superficial acquaintance they may appear to be very simple. Pastoralists are essentially opportunists, not only seeking on a day-to-day basis the best forage and water resources available, but also reacting rapidly to changes in the ecology and the climatic environment of the rangelands that they utilize.

The only too familiar portrait of pastoral communities, propagated by some administrators and development specialists, as innate reactionary and irrational societies, whose members react in a perverse manner to economic incentives, is at best a half-truth. The primary objective of pastoralists is to survive, usually in harsh environments where there is an ever-present threat of destruction of their only means of livelihoodtheir livestock. Given this premise, the members of most pastoral societies are innovative at the

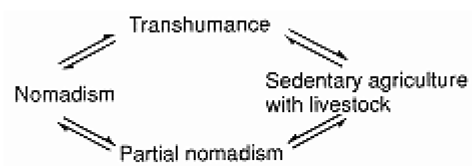

Fig. 7.37
A diagrammatic representation of the continuum between pastoralism and sedentary agriculture.

technological level at which they operate and rational in their short-term economic attitudes.

According to the Overseas Development Institute (ODI, 1976) there were in 1974 about 16 million pastoralists in tropical Africa and perhaps 2 million in tropical Asia. The number at the present time is not known, but despite droughts it is unlikely to be much less than the ODI estimate. The majority of African pastoralists are to be found in the Sahelian zone of West Africa and in East and Northeast Africa, though there are small numbers scattered throughout the drier areas of the continent. In tropical Asia pastoralists are found in Western Asia, the Arabian peninsula and the Indian sub-continent.

Pastoralists breed and manage camels, donkeys, sheep and goats as well as cattle. In a very general manner the importance of cattle in pastoral systems increases as the annual rainfall in the region improves, but in good rainfall years cattle herding increases in drier areas, whilst in drought periods camel herders penetrate into high rainfall areas.

As there is a continuum between systems, they are difficult to classify but some of the more important types are:

• Those of fully nomadic peoples such as the pastoral Fulani (syn. Fulbe, Fula, Fellata and Peul) of West Africa.

• Partially nomadic systems such as those of the Baggara Arabs of the western Sudan who move 'horizontally' in an annual circumscribed manner (Fig. 7.38); migrating southwards in the dry season to the higher rainfall region around the Bahr el Arab and retreating northwards during the wet season to escape the biting flies and the mud in order to graze ephemeral forage in the semi-arid range lands.

• Partially nomadic systems such as that of the Turkana in northern Kenya or the Borana in Ethiopia who move 'vertically' into the more humid higher altitude country during the dry season, returning to the semi-arid lowlands during the wet season.

• Truly transhumant peoples such as the Dinka and the Nuer of southern Sudan who grow crops in their villages during the wet season and graze their livestock in the dry season on pasture land that is flooded during the wet season.

In large pastoral regions such as the Sahel in West Africa or the northeast Uganda/southeast Sudan/southern Ethiopia/northern Kenya/southern Somalia area, several different systems coexist in a fragile, patchwork community, together with subsistence and semi-subsistence agriculturists.

Types of Cattle Used by Pastoralists

In general, the cattle owned and managed by subsistence pastoralists are acclimatized to the harsh environmental conditions in the arid and semi-arid rangelands, produce some milk for their owners even when poorly fed and are very fertile when feeding conditions improve after drought. Attempts during the second half of the twentieth century to introduce a money economy into pastoral areas and the almost unanimous agreement of international and national planners that ultimately the aim of pastoralists should be the production and sale of meat, primarily beef, led to attempts to change the structure and practices of pastoral societies. Some form of ranching rather than communal grazing was advocated as was the introduction of exotic breeds, such as the American Brahman and the Santa Gertrudis, for crossbreeding purposes.

Earlier in the twentieth century ranching techniques had been introduced into the Kenya highlands, some regions of Central Africa, South Africa and isolated areas in other countries and by the second half of the century a number of indigenous breeds had been developed for beef production, such as the Boran in the Kenya highlands, the Mashona in Zimbabwe and the Africander in South Africa. Not all pastoralist indigenous breeds are, however, suited for development as beef producers. Some, such as the Red Bororo of West Africa, are superbly acclimatized to semi-arid climates and nomadic management though poor milk and meat producers, whilst breeds such as the N'Dama and West African Shorthorn are relatively poor producers but are trypanotolerant and can be managed in tsetse-infested regions.

Towards the end of the twentieth century it has become apparent that attempts to introduce ranching practices into the arid and semi-arid pastoral regions of Africa have in general been a failure as less than 5% of African cattle are managed on ranches (Winrock, 1992). Also few exotic breeds of cattle have been introduced, except in highland areas and for special situations, such as the use of Sahiwal for crossbreeding in the Masai rangelands of Kenya. It is likely that the types of cattle used in the future in arid and semi-arid pastoral areas will be improved indigenous breeds and to a more limited extent crossbredsparticularly for improved milk production.

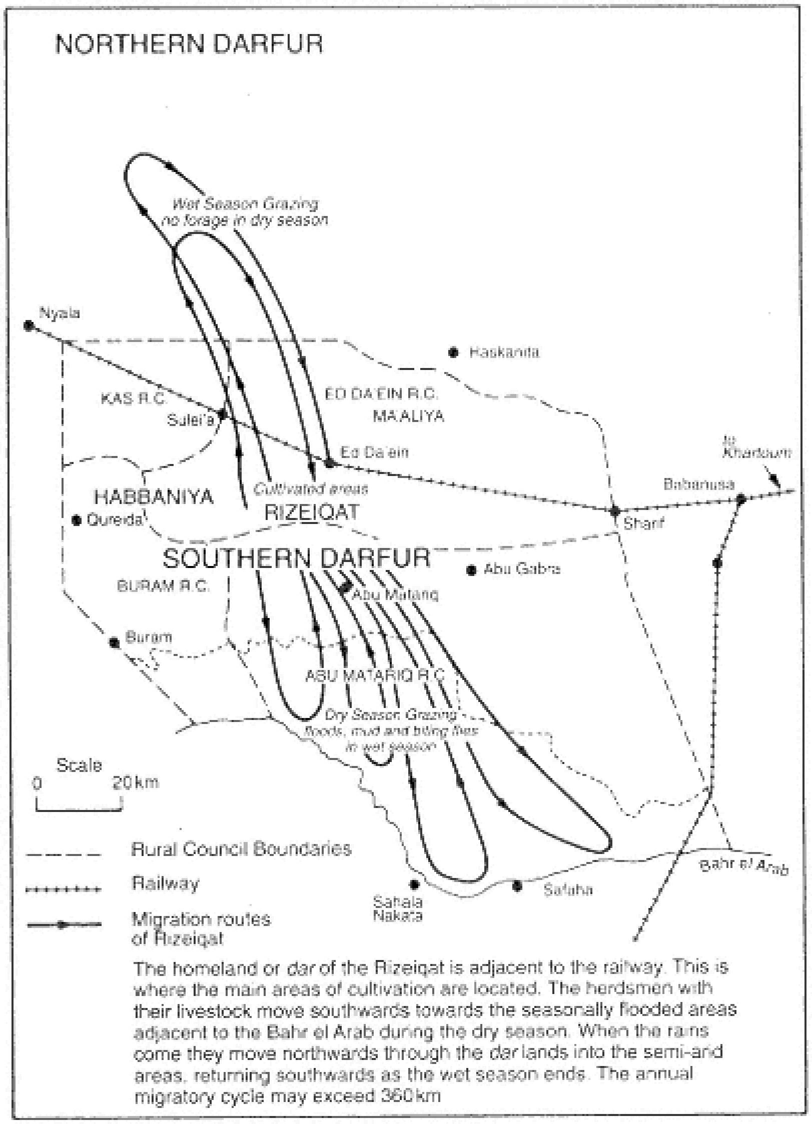

Fig. 7.38
The migratory cycle of the Rizeiqat, a Baggara tribe in Western Sudan.
(Source: Hunting Technical Services, 1976.)

Management and Health in Pastoral Herds

Management.

On account of the diversity of pastoral systems my different managerial methods are used. Nevertheless, pastoral management exhibits some common features.

It is normal for different types of rangeland to grazed in the wet and the dry seasons. Dry season grazings are often swampy or seasonally flooded areas, sometimes far away from wet season pastures.

Most pastoral cattle graze in rather tight groups, moving quickly over the pastures. They often browse as well as graze; indeed, during the dry season the only feed freely available may be browse. They may walk considerable distances during the day, usually drinking at a watering point once in 24 hours. However, if water is scarce they may not be allowed to drink for 48 or even up to 72 hours. Mature cattle are usually

herded by men, whilst calves and sick animals are tended by women and/or children.

At night the cattle are kept in camps. These may be temporary or semi-permanent; the latter may only be occupied seasonally, as Dinka and Nuer camps are in the southern Sudan. Cattle enclosures are usually built using thornbush fences, but in the southern Sudan the Dinka and the Nuer tether each animal using wooden pegs that are spaced in a formal manner around the camp fires. In other pastoral societies each of several classes of cattle may be provided with a separate enclosure.

As feed availability changes rapidly, milk production is a function of season rather than the length of lactation. In the wet season there may be a surplus of milk, whilst in the dry season a precarious balance has to be established between the calf's intake and the off-take for humans. Milk off-take by pastoralists has been estimated to be of the order of 2535% of total production during the first months of lactation (Nicholson, 1984).

The majority of pastoralists milk their cattle twice a day; in the morning before cattle leave the enclosure and in the evening on their return. Calves are allowed to suckle before milking commences; indeed this is essential as the stimulus of suckling is required for milk let-down before milking commences. Calves are then kept apart from cows, but are allowed to graze during day-lighthours usually around the camp. There are, however, exceptions to this practice. In Nigeria Fulani only milk their cattle in the morning, the calves being segregated from their dams during the night, whilst in Mali cows are milked only at night and their calves allowed to stay with them. Milking may be conducted by men only, women, men and children or women only, depending on the mores of the society.

Weaning after a specific period is practised by some pastoralists, whilst others allow calves to wean naturally.

Health

As disease and parasite problems are in general common to all extensive livestock systems these are discussed later in the section concerned with ranching practices. One important difference between pastoralism and ranching is that ranchers can use fenced enclosures to protect their healthy livestock from contact with diseased animals whilst pastoralists have to employ their herding skills to avoid areas where parasites and disease are rife. It is also pertinent to observe that many pastoralists try to ensure that their animals will not suffer from mineral deficiencies by herding them for some part of the year on 'salty grazings', whilst ranchers have to ensure that adequate supplies of minerals are made available in the paddocks.

Productivity of Pastoral Systems

Until the late 1980s it was assumed by the majority of administrators and planners that pastoralism was an inefficient livestock production system. This was partly the result of a general ignorance as to how pastoral systems worked and as to how pastoralists are motivated.

Extensive field research in different pastoral societies (Scoones, 1995) and in particular research directed from the International Livestock Centre for Africa (ILCA) has shown that in certain respects pastoral systems are more productive than ranching systems.

The Borana pastoral system in Ethiopia is more productive than Australian ranches in liveweight gain, protein and energy production per hectare (Table 7.5), but part of this effect may be due to a higher than average rainfall in the Ethiopian system. When the pastoral Borana system is compared with the Laikipia ranching system in Kenya, in which rainfall is of the same order and the same breed of cattle (the Boran) is managed, off-take in terms of liveweight gain is higher in the ranching system but output in terms of protein and energy per hectare is lower (Table 7.5).

Production costs are lower in the pastoral system (Table 7.5) but production per man-day is far higher in the ranching systems, especially the Australian systems. The data provided by Cossins (1985) showing that pastoral systems are more productive on a per hectare basis are sup-

Table 7.5 Comparative production data: pastoralism and ranching. (*Source*: Cossins, 1985.)

System/region	Annual rainfall (mm)	Offtake per ha per year			Production costs (US$)			Production per man-day	
		(kg LW)	(kg AP)	(MJGE)	(kg LW)	(kg AP)	(100 MJGE)	(kg AP)	(MJGE)
Pastoral Borana, Ethiopia	450600 (B)	10.00	2.05	148	0.0230.046	0.140.28	0.170.34	1.04	84
Transhumant, Mali	500 (M)	n.a.	0.603.20	n.a.	n.a	n.a.	n.a.	n.a.	n.a.
Laikipia ranches, Kenya (average)	650 (B)	18.60	1.90	94	0.21	2.01	4.28	2.53.4	116157
Cattle stations, Australia*									
Alice Springs District	300600 (B)	4.95	0.51	24	n.a.	n.a.	n.a.	n.a.	n.a.
Barkly Tablelands	300375 (M)	3.50	0.36	17	n.a.	n.a.	n.a.	n.a.	n.a.
Northern Territory ranches	n.a.	n.a.	n.a.	n.a.	0.200.40	1.933.89	4.088.25	47.053.0	22472515

M = monomodal and B = biomodal rainfall.
LW = liveweight; AP = animal protein; MJGE = megajoules of gross energy available for humans.
n.a. = not available.
* The area grazed is approximately 3050% the total leased.

Table 7.6 Comparative cattle production parameters: pastoralism and ranching. (*Source*: Cossins, 1985.)

System/region	Calving percentage (%)	Calf mortality (%)	Females as % total herd		Total animal biomass (kg liveweight/ha)
			Adult	All	
Borana: pastoral	75	1023	42	66	6473
Masai: pastoral	76	810	3345	6873	3689
Mali: transhumant	56	28	4142	6568	n.a.
Laikipia ranches, Kenya	5283	524	38	62	63125
Cattle stations, Australia					
Alice Springs District	7277	510	37	59	16
Barkly Tablelands	57	510	42	66	13

n.a. = not available.

ported by data from Botswana (de Ridder & Wagenaar, 1984) and elsewhere.

The comparative livestock production parameters (Table 7.6) provided by Cossins (1985) suggest that calving percentages are not very different but that calf mortality is lower and females as a percentage of the total herd are a smaller group in ranching as against pastoral systems. Total animal biomass is higher both in pastoral and ranching systems in Africa than it is in ranching systems in Australia.

The available data appear to show that pastoral systems are more productive on a unit area basis than ranching systems and can thus support more people. This is of very considerable importance at the present time when populations are probably increasing in the pastoral regions. What the data does not show is whether production per unit area and per individual is increasing or decreasing in time, as in the long term this is the essential information that is required.

Problems of Pastoral Systems

There is almost universal agreement that the very existence of many pastoral societies is threatened by radical political, social and economic changes that are slowly denying them the exercise of alternative managerial strategies that were once available. Present pastoral societies are in a sense anachronistic, in a state of decline and threatened with serious, if not terminal, problems.

This is not a new situation, but one that has been incubating for perhaps 100 years. During the 1990s the situation may have worsened on account of particularly severe droughts. It has certainly not been improved by the actions of governments, that in the main have committed themselves to sedentarization programmes, or by those of bilaterial and multilateral development agencies that have promoted development plans that have been often ill-informed and at variance with reality. Many of these plans have been concerned with the production of beef from pastoralists' subsistence milk production herds.

Whatever the causes of the present crisis, the survival of pastoral systems in those environments in which they apparently possess potential economic and ecological advantages, is essential for the governments concerned. These must, together with the pastoralists and the bilateral and multilateral development organizations, resolve:

- How to prevent serious degradation and finally loss of the grazing resource.

- How to fully integrate pastoralists into the cash economy.

- How best to provide pastoralists with essential technical and social services.

Overstocking. How Serious a Problem?

In almost all pastoral societies grazing land is a communal resource whilst livestock are owned individually or by family units. Usually water resources are also communally owned, though in a few societies they belong to individuals, families or clans. The number of livestock owned by the family is therefore not regulated by the carrying capacity of a finite area of grazing land, as it is in the ranching system, but by the managerial abilities and capacities of the family unit. Thus any overstocking in pastoral societies is not the result of ignorance or greed on the part of the pastoralists but is the ultimate effect of livestock management strategies, that given present pastoral social conditions and technology, are essentially rational, economically sound and always a hedge against disaster for the families involved.

If overstocking did not occur in the past, then this was due to the checks imposed by human and animal disease, limited water supplies and local warfare on the growth of human and livestock populations, together with increases in grazing areas resulting from the occasional seizure of land occupied by militarily inferior agriculturists.

The authors have calculated that an average pastoral family of five (adult equivalent units) in the Sudan, half of whose diet consists of milk and milk products, requires 15 livestock units (lsu), equivalents of indigenous cattle to support it throughout the year. Obviously any increase in human population inevitably requires a substantial increase in the cattle population. This has certainly occurred in the Sudan, a country in which the vast majority of cattle are managed within pastoral systems. In 1880 there were approximately 1.8 million cattle with 136 ha of land available per head, whilst in 1980 there were 18.4 million cattle with only 14 ha of land available per head. In addition in 1880 the pastoral lands supported a very large number of wild game that had almost disappeared by the 1980s. During the same period there has also been an increase in the total area of cultivated land.

Given that, as in the Sudan, the human and domestic animal populations of many African pastoral regions have inevitably increased and that by the standards of conventional pastoral ecologists these lands are overstocked, are they being degraded and suffering a permanent loss of economic value? The relative failure of attempts to introduce ranching concepts and systems into African pastoral regions, typified by high levels of unpredictability in climate and forage yield, have highlighted the above question and resulted in investigations into the relative efficiency of indigenous African and introduced rangeland production techniques.

The result of these investigations (Behnke *et al*., 1993; Scoones, 1995) has been to challenge the validity of conventional range managerial theory when applied to rangeland systems that are in a state of disequilibrium, as are many arid and semi-arid systems in Africa.

As a substantial number of African pastoral areas are subject to erratic and variable rainfall regimes, rangeland management in these regions must comprise the calculation of opportunity and the taking advantage of whatever is considered possible. This means responding by herd movement to alternate periods of high and low forage availability, with an emphasis on the exploitation of environmental heterogeneity over a wide area, rather than on the manipulation of the environment within a fixed area as has to be the strategy within ranching systems. Thus in rangeland systems in a state of disequilibrium management must be opportunist, an attitude that has always been embraced by African pastoralists and that is one of the basic concepts of their managerial system. It is a system that in the same environment is used by wild herbivores, who move to exploit environmental discontinuity.

The degradation of pastoral areas that is undoubtedly occurring, the failure of many ranch projects and the data acquired by investigation of pastoral systems during the 1990s suggest that methods of planned intervention into pastoral systems and areas should be reconsidered. In environments where forage availability fluctuates widely there are several possible forms of intervention. These are:

(1) *Provision of forage reserves to provide minimum feed requirements*. Major possibilities are the use of browse and the creation within the pastoral area of a limited number of reserve forage resource sites where fertile soil and water are available. This latter possibility has been used in West Africa.

(2) *Movement of livestock from the pastoral area*. Pastoralists move their livestock from the pastoral areas to utilize crop by-products; a common farming practice in West Africa. There is also opportunity for some stratification as breeding can be conducted in the pastoral areas and fattening in the agricultural areas.

(3) *Reduction of feed intake of pastoral cattle*. Reduction of water intake can markedly reduce the feed intake of ruminant livestock. A method used in desperation by many African pastoralists (see Chapter 1).

(4) *Destocking by sale of livestock*. This requires the establishment of efficient marketing systems, difficult when the supply of animals is erratic; and some form of price incentive, difficult in a period of likely oversupply. Also pastoral families with cash from the sale of livestock need local outlets for the purchase of consumer goods and facilities in which to invest cash surplus to family requirement.

Commercial ranchers can invest surplus capital in the purchase of additional land or in the country's capital investment market. Such opportunities do not exist in pastoral societies where land is communally owned. One outlet in some regions would be crop agriculture, but the most profitable investment is in female livestock. As a consequence surplus capital tends to be invested in the purchase and retention of cows Unfortunately, it is not only pastoralists who invest surplus capital in the purchase of female livestock, but also livestock traders, government officials and crop farmers. The inevitable result can be gross overstocking.

The general consensus is that there are no inherent difficulties in the integration of pastoral societies into the cash economy. It is already happening. There are difficulties in providing pastoralists with adequate educational, medical and other social services, but this is mainly due to lack of resources by governments and the remoteness of many pastoral areas.

The major problem of pastoral societies is to prevent the degradation and ultimate loss of re sources and to slowly improve the productivity of the systems.

The Future of Pastoralism

Livestock systems that exploit the semi-arid rangelands and remain productive without long-term degredation occurring are essential. Existing pastoral systems do not meet these criteria and ranching systems sponsored by international and national agencies have been shown, in general, to be untenable. Nevertheless, changes to the traditional pastoral systems are essential if pastoralism is to survive. Some changes that have been suggested are that:

- Overall policies should focus on the economic and social viability of pastoral communities and not on the production of any one commodity, such as meat.
- Institutional responsibility must be effectively organized at as low an administrative level as is possible in order to ensure pastoralist rights of tenure and their right of access to water, forage trees, etc.
- Where necessary, and possible, transhumance should be encouraged as this system assists pastoralists to establish a 'homeland' where educational, medical, social and other services can be provided.
- The provision of veterinary services at the field level should be the responsibility of the pastoral community with training provided by government.
- The provision of some form of insurance against drought and epidemic disease should be organized so that pastoralists do not have to retain excessively large herds in order to ensure the survival of their basic herd and their family.
- All forms of marketing should be encouraged and tested.
- Pastorlists should be encouraged to invest in alternative opportunities outside the pastoral system.

Despite a plethora of development projects, the above proposals have not in general been evaluated. Overstocking and environmental degradation, with increasing misery for pastoralists, continues unabated. In addition, in several pastoral regions of Africa, civil war together with government financial duress, has led to the complete breakdown of administrative and technical services.

Out of this chaos new forms of pastoralism could evolve, though some may not conform with the changes suggested above. There are signs that enclosure by community and/or individuals is occurring spontaneously in Africa, with reports from southern Darfur, Sudan (Behnke, 1985), Nigeria (Bayer, 1986), Somalia (Behnke, 1988) and East Africa (Graham, 1988).

Crop Agriculture with Extensive Livestock Production

These systems are part of the continuum (Fig. 7.37) between pastoral nomadism and settled agriculture. They include a limited number of migratory shifting cultivation systems and a much larger number of agropastoral or sedentary shifting cultivation systems. Their origins include societies that were once pastoral and sedentary agricultural societies that have acquired large numbers of livestock. They are often termed agropastoral systems.

Migratory Shifting Cultivation

Migratory shifting cultivation is an unstable system. The inputs are minimal and the outputs low. It cannot continue once the human population increases to beyond a certain density. The majority of migratory shifting cultivators only raise small stock and poultry, but there are two regions where cattle are associated with the system.

(1) The savannas adjacent to the forest in West Africa where trypanotolerant cattle breeds such as the N'Dama and the West African Shorthorn are utilized.

(2) Areas peripheral to the rainforest in South America, particularly in the Amazon basin.

In West Africa, owners herd their cattle on communal land adjacent to their temporary cropping areas.

In tropical rainforest areas of South America, where land is privately and not communally owned, some landowners wishing to clear rainforest grant shifting cultivators the right to clear and cultivate shifting plots. The landowners then introduce cattle into the cleared areas behind the cultivators. This is a pernicious system that has led to the destruction of valuable rainforest without lasting benefit for the cultivators or the owners.

Sedentary Shifting Cultivation

Where land resources are limited, where population is increasing rapidly and where there is the possibility of producing and marketing cash crops, sedentary has replaced migratory shifting cultivation. Some or all of these conditions have occurred in the following regions:

(1) Humid forest areas of West Africa and Southeast Asia where perennial tree cash crops have been introduced.

(2) The humid forests of Southeast Asia where valley-bottom rain-fed or irrigated rice has replaced hill rice production.

(3) Fertile alluvial and volcanic soil areas in the humid savannas of Africa where population pressure has been intense and cash crops have been introduced.

(4) The drier savannas of Africa where cash crops such as cotton and groundnuts have been introduced.

(5) The montane areas of Africa, South America and northern India where partial ley systems have developed.

In the humid forests of West Africa and Southeast Asia, shifting cultivation with its cycle of 'fellburnplantabandon' is practised around the villages, but the interval between fellings has of necessity been curtailed on account of increased population and the use of land for perennial tree crops. The result, particularly in Southeast Asia, has been the invasion of the abandoned land by weed grasses such as alang-alang (*Imperata cylindrica*). At this stage shifting cultivators, who previously raised only small stock such as pigs, sheep and goats, have begun to keep cattle and/or buffaloesnot necessarily for work purposes but also for beef and milk production. These livestock owners burn the weed grasses at frequent intervals in order to provide palatable regrowth feed for their livestock and this practice has effectively prevented the regeneration of tree species. The result is that the forest has been replaced by a low-fertility, unproductive, fire-climax grassland (Fig. 7.39). Millions of hectares of humid tropical forest in Southeast Asia have already been reduced to this status and the area increases annually. In South America, the methods by which landowners utilize migratory shifting cultivators to clear their land has achieved the same result, although the fire-climax grassland that results consists of different species, often *Hyparrhenia rufa*, a grass

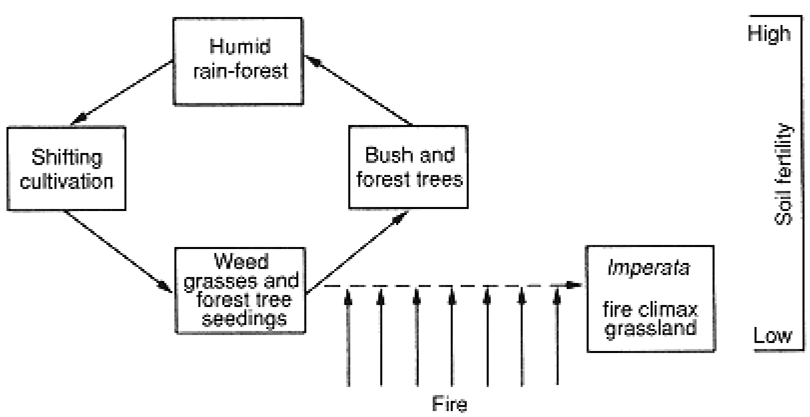

Fig. 7.39
A schematic representation of the degradation process in the Southeast Asian rainforest.

of superior feeding value to *Imperata* spp. In most of West Africa the occurrence of the tsetse fly, the vector of trypanosomosis, has limited the raising of cattle unless the farmers have had access to breeds of trypanotolerant cattle.

On these new, low-fertility grasslands livestock carrying capacity is low and often husbandry is almost non-existent. For example, in some areas in Indonesia where sedentary shifting cultivators are growing tree cash crops, but where there are also large areas of *Imperata* grasslands interspersed with forest bush, the cattle and/or buffaloes sleep under their owner's house during the night and at dawn they trek out into the forest or grassland, returning by themselves at night. Vegetable gardens are protected from these wandering livestock by temporary fences. Inputs are minimal and outputs, both per unit area of land and per animal, are low, but productivity could be rapidly improved.

In those areas of Southeast Asia where valley-bottom rain-fed or irrigated rice has replaced hill rice production a demand for working animals has been created and farmers have begun to raise small numbers of cattle and/or buffaloesprimarily for work, not usually for beef production.

On fertile soils in the humid savannas of Africa cultivation has normally been by hoe. For a variety of reasons attempts to mechanize cultivation have not been very successful and working animals have not been generally introduced on account of the widespread occurrence of trypanosomosis. However, the situation is changing and there is a growing demand for working animals, particularly trypanotolerant working cattle.

Large numbers of livestock are raised in the drier savannas in Africa where cultivation is still mainly by hoe; population pressure has not been too intense in the past and there are still large areas of natural grazings available. Cattle, sheep and goats are bred in these areas; small stock being used for meat and cattle primarily for milk production, though increasing numbers are now used as working animals. Livestock are grazed on crop residues, fallows and natural grazings. Often, during the wet season, the livestock of pastoralists graze the same bush areas as the livestock of cultivators. Pastoralists also graze harvested crop areas at the bequest of cultivators. Unfortunately, a vicious cycle of land and cattle degradation has been initiated in many areas by the introduction of cash crops and by a rapid increase in both human and cattle populations (Fig. 7.40). These events have resulted in increased cash crop cultivation with a consequent decreasing area of bush-fallow available for grazing. However, in the absence of alternative outlets surplus capital has been invested in cattle, and as forage resources have dwindled cattle numbers have increased. This has led to serious overgrazing in the fallow areas, with resulting erosion and an increase in the population of the bush species that are unbrowsed by cattle. The result is an overall reduction in livestock-carrying capacity, unproductive animals, an increase in the labour requirement for bush clearing and the degradation of the bush-fallow area.

Types of Livestock Used.

Migratory and sedentary shifting cultivators will in general continue to breed the indigenous cattle that they already possess or that are utilized by pastoralists in their regions. At present their cattle are triple-purpose animals. Increasing numbers are used for work purposes as animal traction continues to replace hoe culture, females are milked and all end as meat producers. There are few situations where more productive crossbred cattle would be useful in these systems.

It would however, be desirable to increase the use of trypanotolerant breeds of cattle for work purposes in tsetse-infested regions where hoe culture is still the norm.

Management in Agropastoral Systems

In Africa agropastoral systems vary from those of the Fulani in central Nigeria to those of the mixed tribes practising irrigated rice growing in the Niger Delta in Mali. From pastoralists evolving towards settlement to agropastoralists evolving towards complete sedentarization.

The Fulani agropastoralists cultivate small ar-

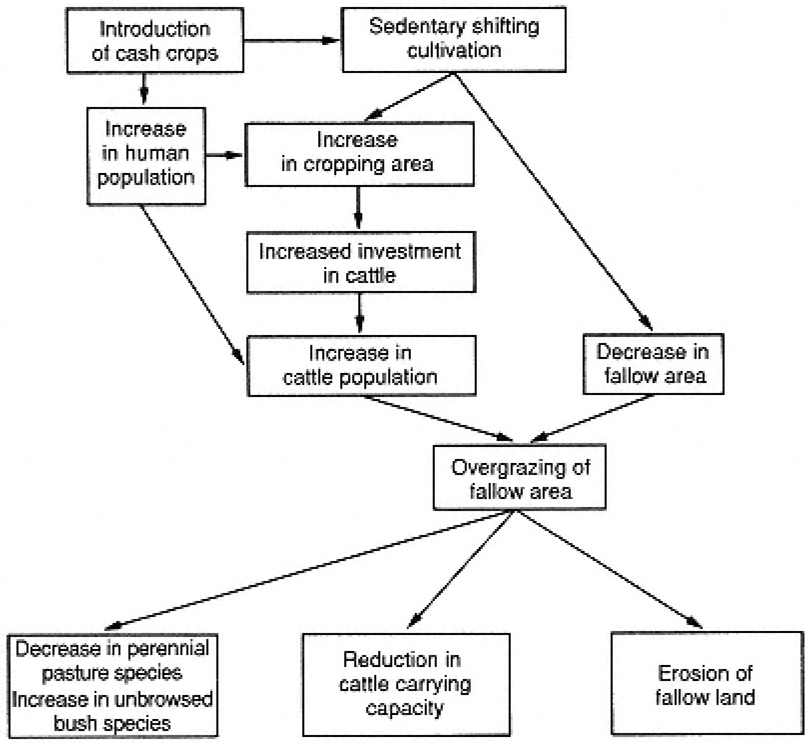

Fig. 7.40
A schematic representation of the degradation process in the dry savanna of Africa.

eas (an average of 0.87 ha per household according to Powell & Taylor-Powell (1984)) and manure the cropped area using their cattle, but continue to rely on neighbouring crop farmers for the bulk of the crop residues consumed by their livestock. During the wet season their livestock are grazed away from the crops of their sedentary neighbours. Bayer (1986) has studied the contribution of different grazing resources to the diet of agropastoral cattle in the sub-humid zone of Nigeria. In the farming areas the contribution of crop residues, browse and range vegetation as a percentage of total grazing time is 12.6, 1.4 and 86.0% respectively. These are pastoralists who are evolving towards settlement. Irrigated rice cropping in the Niger delta is a relatively recently organized agropastoral system in which immigrants from various tribes, pastoral and agropastoral, participate. According to Wilson (1982) four out of five families own cattle with a slightly higher percentage owning ploughs. These agropastoralists are at the opposite end of the spectrum to the Fulani and are evolving towards complete sedentarization. Wilson's (1982) study of livestock production in Central Mali provides considerable information on the interrelationships of pastoral and agropastoral systems and their managerial methods. Within the region there are agropastoral systems associated with rain-fed millet cropping that are mainly subsistence orientated, rain-fed cash/subsistence systems and the irrigated rice system; together with pastoral systems unassociated with any cropping system and others associated with both dryland and irrigated cropping.

In general, agropastoralists rotate their crops in an agreed manner around the communal land, whilst they graze their livestock in the fallow and bush areas during the wet season and throughout the area during the dry season after the crops have been harvested. If fallow and bush land is limited in area livestock may be agisted with pastoralists during the wet season. As populations increase some part of the land may be permanently cropped, usually a 'core' around the village. The rest of the cultivated area being cropped on a shifting system.

At this stage pastoralists may be encouraged to graze their livestock on the village stubbles in order to manure the land for the next crop. Millet-growing agropastoralists in Mali dig wells and provide the pastoralists with water for their livestock during the dry season (Wilson, 1982) in order to attract them to permanently cultivated areas during the dry season.

Agropastoral cattle are subject to the same diseases and parasites as pastoral and ranching cattle but their general health is probably poorer. One reason for this situation is that the grazing time of agropastoral cattle is usually restricted. Bayer (1986), studying an agropastoral system in the sub-humid zone of Nigeria, noted that average grazing time was only 6.1 hour/day. This is probably too short a period for the cattle to obtain sufficient feed, particularly in the dry season. In addition, as grazing areas are restricted and cattle are housed in the same night enclosures for long periods, parasites flourish.

Productivity

Wilson & Clarke (1976) showed that in western Sudan the productivity of pastoral cattle was higher than that of sedentary herds but field research in Mali appeared to show (Wilson, 1982) that the differences are not very significant.

In African agropastoral systems calving rates appear to be of the order of 4560%, cows first calf between 4 and 6 years of age and mature liveweights are not reached until the animals are about 5 years of age. Rates of gain are of the order to 0.150.30 kg/day and calf mortality is in the range of 1530%.

Wilson (1982) suggested that productivity was generally low in agropastoral systems in Mali because of poor calving rates, slow growth rates and high death rates. The limited data available amply support his thesis.

The Future of These Systems

Both the migratory and the sedentary shifting cultivation systems are by their nature transitory and under pressure to evolve into more intensive systems. Quite small increases in human population render migratory shifting cultivation systems operationally inefficient and, as previously stated, such systems are rapidly evolving into sedentary shifting cultivation systems. Additional population increases in the sedentary systems force farmers to use the same areas for cropping year after year and to use more and more of the bush fallow for cropping purposes. The end result of this evolutionary process in many regions can only be the demise of crop agriculture with extensive cattle production systems.

Ranching

Ranching is an alternative to the various types of nomadism and transhumance. In the tropics ranches are found in both the semi-arid and humid regions of Mexico, Central America, the Caribbean and South America; in the tsetse-fly-free areas of East Africa and in Central and South Africa; in Australia and the Pacific Islands; and in small number in specific locations in Southeast Asia, particularly the Philippines. It is the preferred use of land that is inherently infertile, semi-arid or inaccessible and increasingly in Central and particularly in South America it is the prime reason for which large areas of primeval rainforest are being felled and transformed into low-fertility grasslands.

The form of management adopted depends in the first place on the intensity of stocking; this in turn depends primarily on the climatic environment and above all on the total annual rainfall, the seasonal distribution of that rainfall and the repeatability of these factors. In the humid tropics, and particularly in the humid equatorial zone, stocking rates can be as high as one or more livestock units per hectare. In the arid tropics stocking rates may be very low. For example, in northern Australia stocking rates may be as low as one livestock unit per 260 ha, so that ranches have to be very large to remain viable.

The major technical objectives of ranch management are: to maintain and if possible improve the grazings, to decrease annual fluctuations in cattle numbers and seasonal fluctuations in

liveweight, to maximize reproductive performance and to minimize mortality. All these managerial practices tend to intensify production.

In ranching systems outputs generally depend upon inputs, but economic viability may not depend upon maximizing outputs.

Types of Cattle Used

As so many of the original settlers in the present extensive ranching areas of the tropical world were of European origin they stocked their new ranches with temperate-type animals, as these were the cattle that they had known in their homelands.

In the Americas, the first extensive area of European settlement, there were no indigenous cattle and temperate-type animals were imported and became established in the tropical and subtropical as well as in the temperate regions. There must have been considerable losses in the tropical regions, but gradually the imported cattle achieved some form of acclimatization. They slowly evolved in tropical America into the Criollo and Crioulo breeds, discussed in a previous section. In the late nineteenth century the first improved temperate-type beef breeds were imported from Europe and efforts were made to upgrade the Criollo breeds. In general these efforts were unsuccessful. At approximately the same period the first tropical-type zebu cattle were introduced into tropical America. As they were more resistant to heat, drought and tick-borne disease than the exotic temperate-type breeds, they rapidly increased in number.

The present position in the American tropics is that there is an increasing number of high-grade or more or less purebred *Bos indicus*-type cattle available. Three breeds that have originated from a mixture of different zebu breeds may be identifiedthe American Brahman, the Indo-Brazilian and the Jamaican Brahman. In addition, there are three more or less purebred types of Zebu from India that have been acclimatized and improved by selection in Brazilthe Nelore, Guzerat and Gir (Gyr). Several 'stabilized' *Bos taurus* × *B. indicus* crossbred breeds have also been establishedthe Santa Gertrudis, Beefmaster and Brangus, etc., in the United States and the Jamaican Red and Nelthropp, etc. in the Caribbean. A number of semi-stabilized crossbred 'breeds' are also available.

The zebu and crossbred zebu breeds that have evolved or are evolving are having a profound effect on the ranching industry in tropical America and they are being exported to many other tropical countries. They have been used on a very wide scale, particularly in Brazil, Venezuela and Colombia, to upgrade criollo breeds. The first and second crosses between Criollo and Zebu result in cattle that are well acclimatized and yet demonstrate a high productivity compared with the purebred Criollo. The superiority of these crossbreds was attributed to the Zebu *per se*, whereas in reality it was partly due (Table 7.7) to hybrid vigour (Plasse, 1973). As a consequence upgrading has continued on a vast scale, so that today only isolated groups or herds of purebred criollo cattle are to be found in South and Central America and the Caribbean (Rouse, 1977).

In Australia where there were no indigenous mammalian ruminants, the temperate-type cattle breeds that were introduced spread rapidly into the subtropical and tropical areas. They did not thrive as well as was expected, but extensive areas of grazing were available and the incidence of disease and parasites was limited. Some ranchers, realizing the limitations of the temperate-type breeds and aided by the government, imported zebu and crossbred zebu breeds from the United States during the first decades of the twentieth century. The advantages of using these cattle were so obvious that their use quickly spread and is still spreading. An indigenous crossbred beef breed, the Droughtmaster, has now been established in Australia.

With the exception of South Africa, European settlement in Africa occurred much later than settlement in Australia. The temperate-type cattle that were imported into South Africa, where climatic stress was not too marked but disease and nutrient stress were severe, did not thrive too well in many areas so that the early settlers turned their attention to the cattle owned by the

Table 7.7 Estimates of heterosis in a Criollo × American Brahman crossbreeding experiment. (*Source*: Plasse, 1973.)

Characteristic	No. of observations	Mean of Criollo and American Brahman purebreds (kg)	Mean of Criollo × American Brahman crossbreds (kg)	Estimated heterosis (%)
Weaning weight	577			
Males		163	181	11.0
Females		150	164	9.3
Liveweight at 18 months of age	390			
Males		236	277	17.4
Females		214	254	18.7
Average daily liveweight gain	577			
Males		0.666	0.720	8.1
Females		0.607	0.661	8.9

Hottentot. These cattle were indigenous *Bos taurus* × *B. indicus* crossbreds and from these the Africander breed has been developed. This was bred in the first place as a working animal, but with the advent of mechanization the emphasis has been placed on breeding a suitable beef animal and the Africander is now considered to be a beef breed.

The settlers also introduced temperate-type cattle into East and Central Africa, but so many serious diseases are endemic in these regions that introductions into many parts of East Africa were not very successful. Even in the regions of moderately high altitude, some 20 years after the first introduction of temperate-type beef cattle the ranchers realized that they would have to use indigenous cattle. It was fortunate that there was an excellent large Zebu-type animal availablethe Boran. In the short period of 40 years, by selection under improved management and feeding, the Boran has been developed into one of the most productive beef breeds in Africa.

In Central Africa, imported temperate-type breeds were used for a longer period and it was not generally until after World War II that ranchers began to appreciate the potential value of the indigenous Sanga breeds. Although temperate-type breeds still predominate on ranches in Central Africa, there has been considerable development of the use of Sanga breeds such as the Mashona and the Tuli, and the Africander has been imported from South Africa. American Brahman and Santa Gertrudis cattle have also been introduced from North America.

In Asia, for a variety of reasons, development of the ranching industry commenced later than in the other continents. In general, Europeans who had introduced ranching elsewhere did not settle in Asian countries. There is probably no place in Western Asia for an extensive cattle industry. In the Indian sub-continent, where the cattle population is very large, there are social and religious objections to the development of a beef industry. Ranching is most likely to develop in Southeast Asia, particularly in the degraded rainforest areas mentioned in a previous section. The industry is most advanced in the Philippines, particularly in the large island of Mindanao, but a small number of ranches have been created or are being planned in Indonesia, Sabah, Sarawak, West Malaysia and Thailand. It is likely that this is a transient phenomenon as the population is increasing very rapidly in all these countries and most extensive beef cattle systems will inevitably become uneconomic once the land is required for alternative agricultural purposes.

The available evidence with regard to choice of breed in the extensive beef-production regions of the tropics is summarized as follows. In South America it is likely that 'criss-cross' crossbreds exhibiting hybrid vigour will replace many of the existing upgraded zebu herds. In Central America 'criss-cross' crossbreds will also increase in number, but it is also likely that there will be more use of the 'stabilized' crossbred breeds. In the Caribbean the use of 'stabilized' crossbred breeds such as the Jamaican Red is likely to increase. In Australia 'criss-cross' crossbreds and 'stabilized' crossbred breeds of cattle are likely to increase in number. In Africa the use of specific indigenous zebu and sanga breeds is likely to increase and the authors believe that their production could be very rapidly improved by intensive selection. There are special situations in Africa. An attempt should be made to breed more productive trypanotolerant cattle for use in the humid areas of Central and West Africa, and as endemic disease is controlled the breeding of exotic × indigenous 'criss-cross' crossbreeds may become possible, in particular in those areas where levels of nutrition and management can be quickly improved. In Southeast Asia, where the Brahman is being imported to upgrade indigenous cattle, there is a danger that what happened in tropical South America could happen once again, i.e. that all the resulting improvement will be attributed to the introduction of the exotic Zebu. In Southeast Asia it is important to ascertain the productivity of the crossbreds before upgrading systems gain too much momentum, to explore the possibility of introducing other exotic cattle breeds for crossbreeding purposes and to investigate the potential of the Bali breed and *Bos (bibos)* spp. × *B. indicus* and *B. taurus* crossbreds.

Finally, it should not be forgotten that in Central and South America, East Africa and in some countries in Southeast Asia, there is undoubtedly a place for temperate-type beef breeds managed at the higher altitudes. In particular they may be used to provide bulls for 'criss-cross' crossbreeding operations at lower altitudes.

Disease and Parasites under Extensive Managerial Conditions

The disease and parasite situation varies from continent to continent and from region to region within continents. Disease and parasite constraints on productivity are worst in Africa. Not only is a large area of the continent infested with tsetse flies (Fig. 7.41), the vectors of trypanosomosis, but there are more tick-borne diseases than elsewhere, including East Coast fever (ECF), that only occurs in East Africa. An International Laboratory for Research on Animal Diseases (ILRAD), specializing in the investigation of trypanosomosis, ECF and other diseases, has been established, and in association with other national and international research organizations some advances have been made. Control of tsetse flies using insecticides and traps has improved but no method of immunizing against trypanosomosis has yet been found. The 'infection and treatment' method of immunization against ECF has been improved. However, rinderpest has not yet been completely controlled despite the eradication campaign (JP15) organized in the 1970s. New eradication proposals have been made and a more specific campaign has commenced. Foot-and-mouth disease

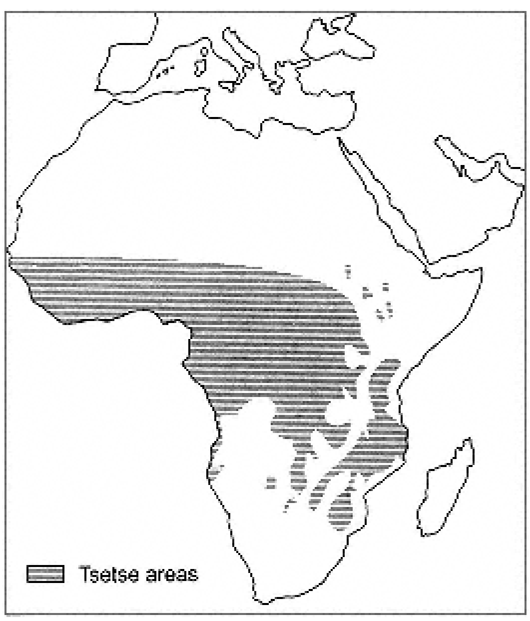

Fig. 7.41

Approximate areas infested with tsetse flies in Africa.

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(FMD) has still not been eradicated and it may not be possible to completely eradicate the SAT strains, as these are carried by the African buffalo. In addition, cattle in tropical Africa suffer from the ravages of most of the diseases and parasites found elsewhere in the world. Calving percentages are very low in many regions and this could be partially due to widespread phosphorus and other mineral deficiencies in the forage. It may be concluded that in Africa disease and parasites are not only a major constraint on productivity in the extensive beef industry but also on the beef export trade.

In the Americas the situation varies from the Caribbean islands, where disease is not a major constraint to tropical South America where disease and parasites are still a serious constraint, particularly on the meat export trade. In Central America, rabies, which may be carried by vampire bats, can create managerial complications. Otherwise the region is free of the major tropical epidemic diseases. In tropical South America there are still many areas where FMD (*aftosa*) is endemic, where calfhood diseases are difficult to control and where the warble fly (*Dermatobiahominis*) known as *nuche* or *torsola* is a major problem.

In Asia rinderpest is under control in most areas and FMD has been eliminated in south Thailand, Malaysia and Singapore and in the major part of the Philippines.

Now that contagious bovine pleuropneumonia (CBPP) has been eliminated in Australia, that country and the tropical islands in the Pacific are free of the major tropical epidemic diseases.

The overall situation would appear to be that epidemic diseases and some external parasites will continue to be difficult to control under extensive managerial conditions, but that with well-planned eradication programmes, improvements in vaccine production and distribution and improved nutrition and management, disease and parasites will cease to be a major constraint on beef cattle productivity, except perhaps in some regions in Africa. It is of course essential that extensive holdings should have available suitable facilities, such as well-planned and constructed yards where vaccination can take place and dip tanks or sprays that can be used for the control of external parasites.

However, some special disease and parasite problems will remain. The incidence of disease and parasites with accompanying mortality will be much higher if the types of cattle used are not acclimatized to their environment. For example, de Pinho Morgado (1961) showed that in Mozambique, under the same conditions of feeding and management, indigenous Landim cattle had a lower mortality rate than introduced Africander cattle, although the latter are indigenous to Africa, and a very much lower mortality rate than introduced Herefords, the differences in the mortality rates being 4.0, 7.5, and 33.3%, respectively. A further interesting observation was that the mortality of crossbred Landim × Hereford cattle, at 5.6%, was lower than that of the Africander cattle.

In the equatorial tropics young calves are very prone to pneumonia in very wet weather. Calf mortality in some areas can be so high that it is worthwhile considering the erection of cheap shelters on the pastures for use by breeding cows with calves afoot.

Tick-control programmes must always be established. Except under exceptional conditions the complete eradication of ticks is considered unrealistic, but some form of tick control is usually needed everywhere, particularly in those regions of Africa where ECF is endemic. Mortality, even of indigenous cattle, can be very high indeed in ECF areas. Stobbs (1966), who reported on attempts to introduce cattle from tick-free to non-tick-free areas in East Africa, stated that the mortality of purebred Boran, crossbred Boran × Small East African Zebu and purebred Small East African Zebu were 77, 43 and 23%, respectively, despite the fact that Small East African Zebu are indigenous to the non-tick-free areas.

Non-trypanotolerant breeds of cattle cannot be herded in tsetse-infested areas without very special precautions and/or the use of prophylactics. The use of the latter is often not economic.

Management and Feeding under Ranching Conditions

There is no single aspect of herd management the adoption of which would lead to maximum efficiency; one improved management practice leads to another and the integration of all gives the best overall results. The most suitable management practices will also vary according to the climatic environment, some of those found to be most suitable in the humid tropics being necessarily somewhat different from those that should be used in the drier areas, although the same basic principles apply everywhere.

Breeding and Reproduction

If productivity is to be maximized under extensive conditions of husbandry it is important that each breeding cow and heifer should produce one calf per year and that this calf should live. Nestel (1965) investigated the relative importance of calving percentage and weaning weight on overall productivity in Jamaica and found that calving percentage was 12 times as important as calf weight in determining output per breeding cow, and that the number of calves weaned per unit area was 25 times as important as the average weaning weight in determining the output per unit area of grazing. The number of calves weaned per unit area is, of course, largely influenced by the stocking rate and by the calving percentage, and as the stocking rate is of necessity low under extensive husbandry conditions the calving percentage becomes of paramount importance.

There is a general impression that the calving percentage in many regions of the tropics is low. In a review of the subject Warnick (1976) estimated that on average it is between 35 and 70%. Plasse (1973) considered that it was between 35 and 60% in the American tropics. In Botswana the Animal Production Research Unit (APRU, 1977) found that the average calving percentage under the traditional system of 'cattle post' management was 47.3% compared with 74.8% on ranches run under 'reasonably acceptable' levels of management. Lamond (1969) noted that in 14 000 cows in the Australian tropics average pregnancy rates were 63%, but that losses between pregnancy diagnosis and branding in a sample of herds ranged from 6 to 40%.

What are the factors that influence calving percentage under extensive husbandry conditions in the tropics? They are many, including the utilization of suitably acclimatized type of cattle, poor nutrition of the breeding females for part or almost all of the year, indiscriminate mating, poor fertility of bulls and too few bulls with the breeding herd.

The type of breed that should be used has already been discussed, and although the advantages of crossbreeding have been stressed, it must be remembered that this practice complicates management. Undoubtedly a greater improvement in a shorter time can be obtained by crossbreeding than by other breeding methods. Nestel (1965) stated that in Jamaica performance testing of existing beef breeds, using the top 1% of all calves born as herd sires, would only improve the genetic merit of the national herd by 1% per annum. Under these circumstances it would take some 20 years of vigorous selection in purebred herds to achieve the same gains that can be made in 1 year by exploiting heterosis, as crossbred calves wean 1520% heavier than purebreds.

If the breed that is utilized is not fully acclimatized the calving percentage may be low and the mortality high. McCarthy & Hamilton (1964), for example, in a survey of extensive holdings in central Queensland, showed that calving rate is higher, mortality lower and the age of 'turn off' of zebu crossbreds significantly lower than that of temperate-type purebred cattle. Warnick (1976) has also stated that systematic crossbreeding increases calf production per breeding cow. The effect of nutrition on calving rates can be very marked in the drier areas of Australia, the Americas and Africa. Low total nutrient intake or a deficiency of protein and/or minerals may so reduce the calving percentage that the cattle may calve only every 2 years or even less often. In areas such as these the feeding of supplements can be a very effective way of improving the calving percentage. Steenkamp (1963) demonstrated that in Zimbabwe the calving percentages of supplemented and unsupplemented breeding cows on extensive grazings were 81.3 and 56.7%, respectively, and that birth weights were lower in the unsupplemented group, while Bauer (1965) showed that in South Africa supplements to 3-year-old heifers raised the conception rate at 4 years of age from 12.9 to 83.5%.

It is generally conceded that heifers should not be bred too early as this practice may reduce the calving percentage. Indiscriminate mating, which frequently happens when the cattle on a holding are managed as one herd, has been thought to lead inevitably to the early breeding of heifers. Bauer (1965), however, suggested that indigenous cattle in South Africa do not naturally breed until they weigh at least 250 kg liveweight, and that early breeding does not affect the lifetime performance of tropical-type beef cattle if there is a long interval between the first and second calvings. General observations on indigenous tropical cattle managed according to traditional standards tend to support Bauer's thesis. The danger is that when attempts are made to improve the productivity of indigenous herds, earlier matings are encouraged without the provision of alternatives to the compensating factors present within the indigenous managerial systems. When attempting to improve productivity in indigenous breeds it is necessary to set a weight-for-age standard for the first service of heifers.

Another important consideration is whether the herd bulls are able to serve all the cows and heifers that are likely to come on heat at any one time. Under ideal conditions the fertility of herd bulls should be tested but this is, of course, difficult if not impossible on most extensive holdings.

What is important is to see that there are a sufficient number of bulls available, assuming that some of them may be sterile or lazy. In the temperate zone it is generally advised that 3% bulls in the herds should be sufficient although on larger properties 56% may be required, but in the tropics, where the topography may be very rough and the climatic environment stressful, an even higher percentage of bulls may be desirable. If the employment of these additional bulls ensures a high calving percentage, then although the practice may appear wasteful it could, in fact, be very economic.

As intensification proceeds on extensive holdings the breeding programme should also be intensified. Suggestions from Australia on methods of intensification can be useful in all ranching areas in the tropics. Three stages of intensification have been defined in Australia. First, heifers should be segregated from the other cattle and run as a separate herd for mating purposes. In Australia this operation would be carried out when the heifers are 2.5 years of age, but in many other regions it might be carried out when the heifers are somewhat older. Secondly, heifers should be segregated from the main herd when they are weaned and given a choice of better feed so that they can grow more rapidly and be ready for first mating at an earlier age. In the third stage the heifers should be segregated at weaning, fed slightly better than other cattle and mated during a controlled breeding season of 3 to 4 months. A further refinement at this stage would be to pregnancy test the heifers after the mating season and then rigidly cull all non-breeders and at the same time feed all pregnant heifers and cows pre-calving feed supplements.

The advantages of intensifying the breeding system in these ways are that:

(1) The nutritional demands of the breeding stock can be synchronized to some extent to the seasonal production of feed.

(2) Marking, weaning and dry season supplementation can be simplified because of the uniformity in the stage of pregnancy and lactation of the heifers and cows, and in the age of calves.

(3) Heifers can be prevented from calving at too young an age, thus reducing the dry season loss of first-calving heifers and the production of small, underweight calves.

(4) After mating bulls can be kept close to the yards where they can easily be fed supplements and where fertility testing can be undertaken and tick control simplified.

(5) More or less uniform groups of cattle become available for marketing at specific times.

(6) Artificial insemination (AI) and other techniques can more easily be used for upgrading purposes.

The disadvantages of intensification are as follows:

(1) Insufficient information is often available as to the most suitable time for calving so that it is easy in theory but difficult in practice to synchronize the nutritional demands of the cattle with the production of feed. This is particularly true in the very dry areas where seasonal climatic variations may be very marked.

(2) There are indications that many cows calve later each succeeding year, requiring more than 12 months between calvings and thus jeopardizing the controlled breeding programme.

(3) Bulls that are segregated for 8 to 9 months of the year may not work too well during the early part of the mating season.

(4) The system requires more capital. This is, of course, one of the difficulties of any form of intensification.

It is generally thought that in the ranching areas of the Americas and Australia the advantages of a controlled breeding programme outweigh the disadvantages. In Australia it is said that by the use of a controlled breeding programme it is possible to achieve a calving percentage of 7080%far higher than is normally achieved on extensive holdings.

In many tropical regions, and particularly in Africa and Southeast Asia, there is at present such a lack of production and other data that controlled breeding programmes should only be introduced after intensive investigations, and then only with caution.

The use of AI techniques for upgrading purposes has been suggested. Although it is difficult to utilize the ordinary AI techniques to any major degree on extensive holdings it is possible to use them with modifications. The most satisfactory method is to gather a limited number of the most productive beef breeding cows on to a small area of the holding, to synchronize their oestrous cycles and then proceed to inseminate them over a short period. Using this technique an upgrading programme can proceed very rapidly in a small, specially selected 'nuclear' herd. This 'nuclear' herd can be kept for the production of 'improved' bulls that are subsequently used in the breeding herds out on the extensive grazings.

Feeding.

Major problems encountered in the feeding of extensively managed cattle are mainly those that directly result from seasonality in the growth of pastures and fodder. This adversely affects productivity and complicates management in both the dry and the humid tropics.

In the dry tropics seasonality in forage productivity can be very great and often there is no production at all for long periods. This very marked fluctuation in the availability of feed produces the well-known cyclic growth pattern in extensively managed cattle (Fig. 7.42). The cattle grow during and immediately after the rainy season, and maintain or lose liveweight during the remainder of the year. It can be seen from Fig. 7.42 that had the cattle continued to grow at the same rate as they grew in their first 10 months of life, they would have achieved their 40-month-old liveweight at approximately 20 months. After an exceptionally long dry season, cattle may continue to lose weight during the first weeks of forage growth at the commencement of the rains (Fig. 7.43). This phenomenon is known as the 'green-grass' loss and is well known in East Africa where it has been studied (Payne, 1965). Under conditions of cyclic growth there is often accelerated growth when feed becomes abundant during the wet season. This is known as 'compensatory growth', a phenomenon that enables an animal with a retarded growth rate to catch up with the final liveweight of contemporary unretarded animals, often with the advantage of superior food conversion for the period of most rapid growth. Information on this subject

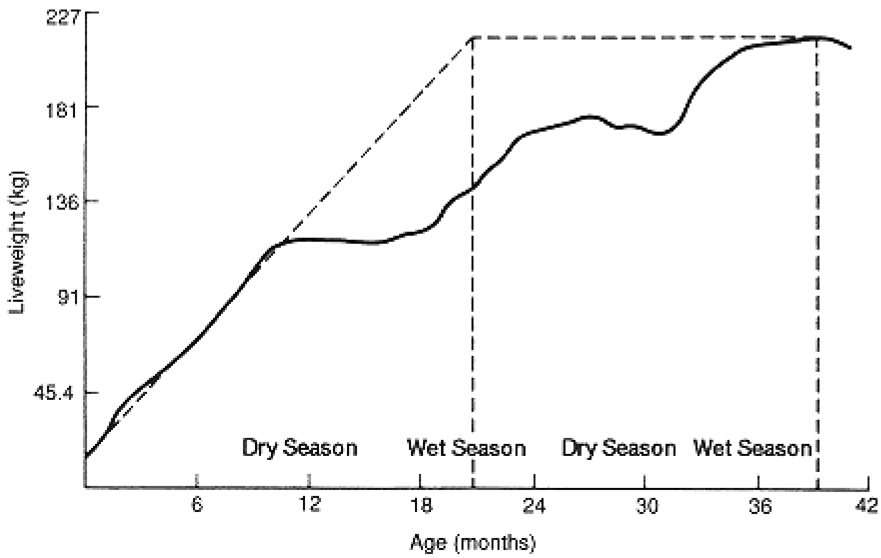


Fig. 7.42
The cyclic growth pattern of extensively managed cattle.
(Source: Touchberry, 1967.)

has been reviewed by Wilson & Osbourn (1960) and further discussed by Butterworth (1985).

However, some of this 'compensatory growth' may be more apparent than real. Part of the additional gain may be due to the retention of additional water in the body tissues, just as some of the weight loss during the dry season may be due to loss of water that in the wet season would be retained in the body tissues. Taylor (1959) has shown that some of the reported increase in liveweight is due to an increase in the weight of 'fill' in the digestive tract. Nevertheless, Smith & Hodnett (1962) stated that in the natural veld areas of Zambia cattle that have experienced large weight losses in the preceding dry season consume more herbage in the following wet season than cattle that have received supplementary rations during the dry season. This work suggests that some part of the 'compensatory growth' could be real.

There is another factor to consider. As Montsama (1967) has stated, 'compensatory growth' may compensate an animal for loss of weight during periods of under-nutrition, but at the same time the animal ages and becomes physiologically more mature and the normal pattern of growth and development may be disturbed. As might be expected, restriction on growth followed by increases in growth rate will have the most effect on the later maturing tissues, particularly on fat. As a result *Bos taurus* and *B. indicus* cattle may differ markedly in their carcase response to compensatory growth.

Opinions vary as to the age at which compensatory growth is most effective. Montsama (1967) stated that it is highest in young cattle while Smith & Hodnett (1962) considered that it was least in cattle under 2 years of age.

As far as the effect of breed is concerned, it is generally considered that slower maturing types of cattle respond better in terms of compensatory growth after a period of under-nutrition than do faster maturing types. This suggests that in areas where cattle are subject to periodic under-nutrition the slower maturing indigenous breeds may have an advantage over rapidly maturing exotic breeds.

The effects of seasonality in forage production on the growth of beef cattle are fundamentally the same in all those areas of the tropics where there is a definite dry season. In fact, everywhere except in the equatorial tropics. The practical results vary in accordance with the length and severity of the dry season. However, even in the

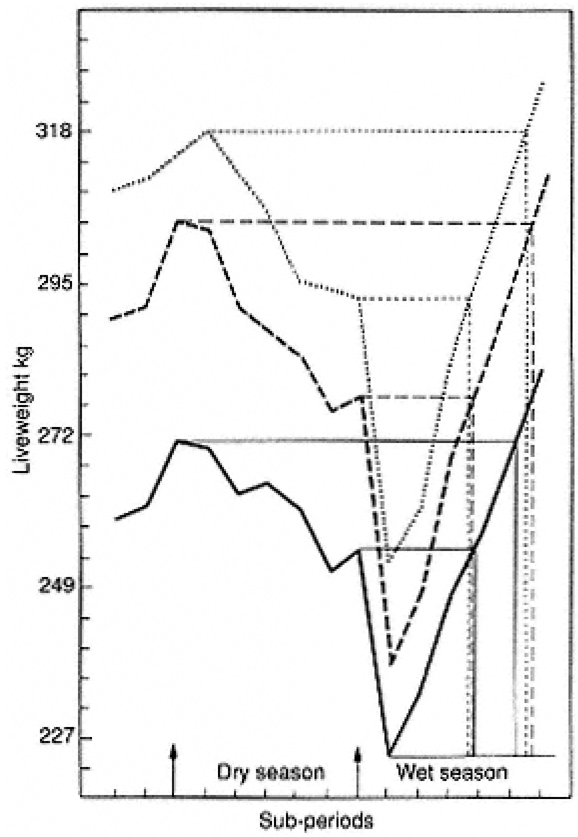


Fig. 7.43
'Green-grass' loss in liveweight for various groups of cattle at the end of the dry season.
(Source: Payne, 1965.)

humid tropics where planted pastures are grazed, seasonality in production can still create managerial problems.

What are the possibilities of 'ironing out' major fluctuations in the supply of forage on extensive grazings? Any practice that may be adopted must, of course, have an economic basis, and this is a major difficulty as many practices that might be economic on intensive cattle farms are almost certain to be uneconomic on extensive holdings. The practices that have been suggested and might be adopted vary both within and between countries according to the climatic environment, the topography, the type of cattle utilized, the intensity of stocking, etc. Methods that have been suggested may be classified into two groups. The first consists of those in which changes in the management of the cattle are necessary and the second of those in which there is manipulation of the feed supply.

Some cattle managerial methods that might assist are, firstly, adoption of a seasonal breeding programme designed to correlate the period when there are the maximum number of animals on the holding with the season when the feed supply is at a maximum. As stated previously, a seasonal breeding programme can only be adopted when there is some degree of intensification. It is usually suggested that seasonal breeding should be programmed so that the breeding cows calve just before or just after the wet season commences when the amount of forage present is at a maximum and when the breeding cow's nutrient needs are highest. This appears to be sound advice in those regions where the wet season is short, but in the more humid areas calving at this time might lead to increased internal parasitism and possibly higher mortality in the young calves. In the equatorial regions where there is rain every month it may be very difficult to decide which is the most suitable month to calve.

Another suggestion where seasonal breeding is practised is to arrange the calving period so that the calves are weaned when feed is at a maximum. The difficulty of operating this system is that the breeding cows would then be calving during the dry season and may not milk too well, while they would be dry when feed was most abundant. Secondly, the total number of cattle in the herd may be reduced before the dry season commences by culling non-fertile cows and heifers and by selling steers. The latter may be a good managerial practice in some monsoonal areas where the wet and dry seasons are often of almost equal length, but it would not be a very practical system in the very dry areas where the wet season is very short. A major advantage of this managerial practice is that steers are sold before they lose weight, as will inevitably occur during the dry season.

Some managerial methods by which attempts may be made to manipulate the feed supply in order to 'iron out' major fluctuations are, firstly, grazings may be improved so that they remain green longer into the dry season and grow away faster when the rains come, thus lengthening the period during which feed supplies are adequate. It is probably easiest to do this in the monsoonal and savanna areas as it is often impossible to improve pastures in any economic way in the semi-arid areas.

As legumes often continue to grow during the drier periods when grass growth has ceased, the use of legumes, particularly in the monsoonal areas, may reduce seasonability in forage production to a limited extent. Legumes may be encouraged on extensive grazings by dispersing treated legume seeds from aircraft, moving vehicles or from horseback, or if the legume seeds possess a hard outer shell by feeding them to the cattle from strategically located feeding boxes. The cattle will then spread them around the grazings as they defecate. Butterworth (1985) has effectively reviewed the use of legumes in improving the productivity of extensive tropical pastures.

Another method is to improve a small area of pasture close to a holding area, possibly by the use of irrigation and fertilizers. This is really intensification on a very small part of an extensive holding, and in the drier regions the intensive cultivation of grass and/or legume fodder crops can sometimes be a very economic method by which the total amount of forage available to the beef herd can be increased during the dry season. The small area of improved pasture can either be fed off directly, green-soiled or the forage can be made into silage and/or hay and fed when required. The most desirable practice would be to use these small areas for the feeding of those classes of stock that would benefit most from supplementary feeding, such as the weaners. This method is practised in tropical Australia and various reports suggest that it can be very effective in improving the liveweight gain of beef cattle. Sutherland (1959) reported that the feeding of 0.9 kg of lucerne hay per day for 100 days to steers during the dry season enabled them to gain an extra 33 kg liveweight over a control group of steers that received no supplement. It has also been reported from Queensland that cattle with access to 2 ha of lucerne between May and August in a 12 ha field gained 39 kg while a control group with no access to lucerne lost 9.5 kg during the same period.

Another desirable managerial practice might be to plant browse for use during the dry season, as browse plants usually retain their leaves and even when the leaves are shed the dry leaf is still good feed and will be picked up and eaten by the cattle. In practice, in the very arid areas, cattle live almost entirely on browse as there is usually no other feed available except for very short periods when annual grasses and herbs thrive during the rains. Browse production and utilization in Africa is discussed in an ILCA publication (Le Houérou, 1980).

Secondly, the problem of supplementation of rough grazings during dry periods has received considerable attention in Australia, the Americas and in Central and South Africa, and many suggestions have been made as to how this might best be accomplished. The subject has been comprehensively reviewed by Butterworth (1985), who collated experimental data from all regions of the tropics on protein and energy supplementation of growing and breeding stock and the use of non-protein-nitrogen (NPN) as a supplement. He concluded that in the majority of trials, supplementation of growing stock resulted in liveweight gains, that there was some evidence of improvement in carcase quality and that supplementation could result in a pasture sparing effect. He also noted that the effects of supplementation on growing stock could be nullified at a later date by compensatory growth. Supplementation of breeding cattle, lowered age at first calving, increased calving percentage, led to a more rapid return of oestrus after parturition, improved milk production and decreased mortality, but was most economic at a low level. He noted that there are major differences in response when NPN is used as a supplement.

Economic methods of utilizing supplementary feeds would certainly revolutionize beef-production methods in the extensive areas. As will be seen from Fig. 7.42, cattle that would not normally attain a slaughter weight of 250 kg until they were 3.5 to 4 years of age could be 'turned off' at around 2 years of age if they were fed supplements during the dry season that enabled them to gain 0.5 kg per day. As McDowell (1966) stated, it is likely that supplementation would be most economic if supplements were fed at the end of the growing animal's second wet season, with the aim of turning them off at 2733 months of age.

Another feeding problem in many parts of the tropics is that cattle on extensive grazings encounter deficiencies of major and/or minor mineral elements and that these deficiencies are usually intensified during the dry season. Mineral deficiencies on extensive grazings and mineral supplementation is fully discussed by Butterworth (1985) and McDowell (1985). Deficiencies can be prevented by the provision of minerals. These may be fed from strategically located boxes that should be provided with a roof to give protection from the rain during the wet season, as ingredients in molassesurea blocks, or they may be added to the water-supply system.

Stratification and Stocking Rates

It is desirable to practise stratification not only between but also within holdings. On large holdings, and elsewhere if possible, the breeding cows with larger unweaned calves afoot, the heifers that are of sufficient age or heavy enough for first mating, together with the non-working breeding bulls should be rotated around the nutritionally poorest sections of the holding. The nutritionally better sections should be reserved for the fattening of steers and for growing-out the younger heifers and bulls. The importance of this strategy is emphasized by the evidence presented by Nestel (1965) that in Jamaica 280 kg per ha of liveweight was produced by the breeding herd compared with 706 kg per ha by fatteners, and that the profit per unit area was correspondingly higher. The reason for this result is that at any one time a large percentage of cattle in the breeding herd utilize feed for maintenance rather than for production purposes.

As the major problems encountered in the feeding of extensively managed beef cattle are mainly those that directly result from seasonality in the growth of pastures, it is absolutely essential that the rancher or pastoralist should make a realistic estimate of the carrying capacity of his land. In the arid and semi-arid tropics this must be determined by carrying capacity in the dry season, while in the humid tropics the stocking rate must be sufficiently high to keep forage growth under control. Experience has shown that this is one of the most difficult estimates to make. In the dry tropics it is almost impossible to determine for a few seasons in advance what the carrying capacity is likely to be in the long term, therefore the cautious grazier should deliberately understock during the first few years of occupancy. In the humid tropics it is only too easy to understock, so that the forage gets away from the cattle and has to be burnt off.

Control of Animals, Grazings and Water

The grazier must have complete control of his herds, so that they can be handled quickly and efficiently and can properly utilize available feed and water. This means that the must have suitable handling facilities such as yards, races, dips, etc., and that these should be strategically sited and strongly constructed. Well planned and constructed handling facilities reduce the number of accidents to cattle and men and improve efficiency of labour utilization.

As intensification of production increases, control of the herds must be improved and this means more separate herds and, consequently, more internal fencing and handling facilities. On poorly managed extensive ranches there is often only one herd. This is bad husbandry and considerable improvements can be made in productivity by simply segregating various types of cattle. As stated previously the minimum number of herds should be three, but even this degree of segregation is often difficult to achieve. The very least that can be done is to segregate the weaned heifers and castrate all surplus bull calves. On more intensive holdings, young bulls should be run separately from the steers and old bulls, and the steers should be divided into two or more groups according to age.

The grazier must also develop a grazing system that encourages the production of palatable and nutritive forage species and discourages the growth of weeds or soil erosion. The amount of subdivision required varies according to circumstances, but, in general, much greater subdivision is required in the humid than in the dry areas. Whether the grazier fences or uses herdsmen depends on the availability and cost of labour, but he also has to decide whether he will set-stock or rotationally graze. The general consensus of opinion is that paddocks in the drier areas require 'spelling' or they will deteriorate, and that rotational grazing would appear to be almost obligatory in the more humid areas if the grazier is going to take maximum advantage of the rapid growth of forage.

Rotation and the 'spelling' of paddocks have other advantages apart from those concerned with the utilization of forage. In drier areas 'spelling' can improve tick control as ticks can be almost eliminated from a paddock after a minimum period of 4 months without grazing animals. The concentration of cattle in one area also improves the operation of the breeding programme and assists in the efficient handling of stock.

Whether the cattle are fenced or herded, rotationally grazed or set-stocked, every effort must be made to see that they graze evenly over the grazings and do not 'eat out' any one area, particularly around sources of water. The provision of water can itself be used as a method of controlling stocking rate and cattle movement on large holdings. Water sources should be separately fenced so that the utilization of water can be controlled.

On very extensive holdings it is only practical to gather the cattle occasionally, often only once or twice a year, when calves are weaned, marked, castrated, dehorned, inoculated, dipped, etc.

Weaning

There are different opinions as to the most suitable age for weaning. Some graziers like to wean early, at from 6 to 7 months of age, in order to ensure that their cows breed annually. There is evidence that this may not be a desirable practice in some of the drier areas (Steenkamp, 1963), but it may be a reasonable practice in the humid areas, particularly where the grazings have been improved.

Calves should certainly be weaned by the time they are 9 months of age. Once calves have been weaned, they should be run as a separate herd and rotated round the best grazings. In the humid tropics, where rotational grazing may be practised, the calves can be rotated in front of the breeding herd. In the drier areas it may be more difficult to ensure that they have a high nutrient intake and it may be necessary to provide supplements during the drier weather.

Marking

This usually takes place at weaning. Different methods of marking are discussed in Appendix I.

Castration

On extensive holdings castration is usually carried out at weaning. Where cattle are herded it could, with advantage, be accomplished earlier. In fact, the earlier the better. In many tropical countries, castration is carried out very late, often when the cattle are 4 years of age.

It has been suggested that in most tropical countries where there is no premium for the production of high-quality beef there are no advantages in castrating bulls that are going to be sold for meat, particularly as bulls normally grow more rapidly than castrates. MacFarlane (1966) investigated this problem in Tanzania using the Small East African Zebu and found that in this breed castration had no positive effect on growth or on carcase composition.

Dehorning

This is usually accomplished at weaning on extensive holdings, though like castration it might better be carried out at an earlier age. There are no advantages in dehorning range cattle unless the horns of the adult cattle are so large that the cattle cannot pass through spray races, etc.

Animal Health Practices

The number and type of inoculations and vaccinations required will vary from country to country according to the local disease situation. Drenching of range cattle is not usually required.

Dipping or spraying by machine or by hand is essential in tick-infested areas. The frequency required depends on climatic factors such as humidity and the pattern of rainfall. In the humid areas it could be necessary throughout the year, but in the drier areas it may only be necessary during the wet season. It is usual to endeavour to keep tick infestation under control and not to attempt to eliminate the ticks. Where cattle are frequently handled, hand removal of ticks can be a very efficient form of tick control.

Special Problems of Remote Areas

One advantage of the extensive beef cattle industry is that it can economically utilize land in remote areas that would otherwise remain unproductive. However, the very remoteness of many extensive cattle grazings does create special problems for the rancher. These are mainly concerned with the transport of pastoral requisites to, and fat or store cattle from, these remote areas. Remoteness also creates special social problems which, apart from their effect on the supply of labour to the industry, are generally outside the scope of this text.

In Australia these problems particularly beset the cattle industry in the far north of the country. In South America the problem is continent wide, but particularly affects the industry in the *llanos* of Venezuela and Colombia, and in the interior of Guyana and Brazil. In Africa cattle are raised in the savanna regions that are often remote from centres of population, and separated from them by tsetse-fly-infested country. In the Philippines and in Indonesia in Southeast Asia the sea acts as a barrier as cattle may be raised on one island and the major beef consumption centres be located hundreds of miles away on other islands.

Of course the provision of transport is the answer to these problems, but one of the difficulties of providing an adequate road or rail transport system or even adequate sea transport in archipelagos is that the total quantity of goods to be transported is low in relation to the distances involved, and that the number of cattle to be transported fluctuates widely from season to season and from year to year.

Traditionally, cattle have been trekked from the remote areas to railheads or to centres of population. Even when trekking routes with watering facilities are provided by the goverment this has always been a wasteful method of transport as fat cattle lose considerable weight and condition on their way from production to consumption centres. This reduces producers' incomes and, consequently, their ability to effect improvements on their holdings as cattle are usually retained until they are over-fat, thereby reinforcing overstocking and low off-take problems.

Since the 1960s there has been a revolution in the transport of cattle as road networks have improved. In Colombia, for example, the trekking of fat cattle from the northern coastal plains to the inland market of Medellín has virtually ceased and all cattle are now trucked. This revolution in the transport of cattle is one of the preliminary steps that have to be taken towards the modernization of the beef industry in these regions, and holds the promise that extensive improvements on the grazings and in management will ultimately be considered to be more worthwhile.

There are, however, some remote areas where the road network may not yet be improved for several decades and where there are no possibilities of transporting by water or by rail. In these areas the slaughter of cattle in the producing areas and the air freighting of carcases to centres of production may be economic. This method has been used in one area of northern Australia where carcases have been flown from the Glenroy Works in the Kimberley region, in the north of Borneo where carcases are flown from the highland interior to the coast and in the orient region of Bolivia from which carcases have been flown to the highlands. Air freight is, of course, necessarily more expensive than other freight methods, so that producers' receipts are lower, but it may still be cheaper for the producer than the losses incurred on the long treks to railheads or to all-weather roads. Slaughter in the production area also, of course, raises problems with regard to the economic disposal of offals.

In the past the meat industry in developing countries has been less than enthusiastic about any move to locate abattoirs and meat-packing plants close to centres of production. The whole problem should be re-examined and if an economic type of low-throughput abattoir can be designed then slaughter of cattle on a relatively small scale in the production areas may become economic, and the transport problems of the remote areas would be easier to solve.

The Future of Ranching.

It is likely that the ranching industry will slowly contract on the more productive lands and that beef production will become more intensive as population increases. Ranching is, however, likely to continue as a major system in less productive areas, particularly in semi-arid environments. Changes that have occurred in Kenya may be illustrative of what is likely to happen in general in Africa. Despite the very high and even emotive demand for land, ranching has continued in most semi-arid districts and where semi-arid ranch land has been subdivided for agricultural purposes, experience now suggests that this was a mistaken policy. On the other hand, the land of pastoralists in better watered districts, such as the higher areas of Masailand is beginning to be used for agricultural purposes, despite traditional pastoralist attitudes with regard to the use of land.

In tropical Australia ranching is likely to continue to be the major livestock system as it will also continue to be in the drier regions of tropical America. However, in the Asian equatorial tropics where there is little ranching at present and in the equatorial tropics in the Americas where forest has been wastefully felled on a vast scale to provide land for ranching, it is likely to be superseded by a system that is more capable of efficiently exploiting these environments.

Semi-Intensive Systems

Crop Agriculture with Livestock Production

In some respects this is the most important cattle production system as it probably includes about half of all cattle reared in the tropics, together with large numbers of buffaloes and some sheep and goats. The word 'probably' is used deliberately as in some countries, and particularly in those of the Indian sub-continent, a varying proportion of cattle included in the system are owned by landless labourers.

The present systems have probably evolved from pastoralism, through shifting cultivation, in the drier areas and from shifting cultivation in humid forest areas, as increasing human population has reduced the area of available land per family. Without the introduction of new economic factors such as industrialization the size of holdings will continue to shrink and the landless population to increase.

The system is characterized by:

• The relatively small size of holdings (Table 7.8).

• A mixture of subsistence, semi-subsistence and cash economies, though total subsistence economies have almost disappeared.

• The use of cattle primarily for work purposes, though increasing emphasis is being placed on their use for milk production in many countries; particularly those in South Asia.

• The use of old working cattle and culled milking cows for meat production, except in Hindu cultures.

• An emphasis on the use of agricultural and industrial waste products and cultivated browse as feeds rather than on pasture and/or range.

The system is of importance in:

• Some regions of Africa: particularly Senegal and northern Nigeria in West Africa; Uganda, western Kenya and central/west Tanzania in East Africa; parts of Ethiopia and specific areas of Central Africa.

Table 7.8 Farm and draught animal data for some Asian countries.
(*Source*: adapted from Ramaswamy, 1985.)

Country	Average area of arable land per farm (ha)	No. workers per ha	Total draught animal population (000)	
			Cattle	Buffaloes
India	2.62	0.90	110 000	16 000
Philippines	3.66	0.71	600	3000
Sri Lanka	1.59	1.20	n.a.	292
Thailand	3.64	1.10	3000	5000
Vietnam	1.57	2.10	n.a.	n.a.

n.a. = not available.

- Monsoonal South and Southeast Asia.
- Irrigated areas in the dry tropics.
- Tropical islands in the Caribbean and the Indian and Pacific oceans.
- In countries throughout the humid and subhumid tropical regions of Central and South America.

General features of the system are described below, including details of the present emphasis on the development of dairyingparticularly in South Asia. Specialist dairying features, some of which could be introduced into the system, are discussed in the section entitled 'Modern sector cattle production'. Details of the husbandry of working cattle, which are such an integral and important part of the system, are discussed in a later section and in Chapter 21.

Types of Cattle Used

In general sedentary farmers everywhere use the type of cattle that are locally available. In Asia and Africa these will be the indigenous breeds discussed in a previous section. In many Asian countries buffaloes are used for heavy field work whilst cattle are used for lighter tasks. In the Americas and the Oceanic islands the type of cattle used will depend on what breeds have been introduced. Often the cattle used will be *Bos taurus* × *B. indicus* crossbreds.

In countries where milk production is promoted amongst sedentary agriculturists and where the indigenous cattle are poor milkers of the *Bos indicus* type, *Bos taurus* type milking cattle are being introduced. These are primarily used for crossbreeding, but attempts are also being made to establish purebred herds. If disease and parasites are well controlled, the climate not too extreme, feed resources fair and management of a reasonable standard then *Bos taurus* type cattle may acclimatize. The conditions listed are, however, exceptional. In general, herds of purebred *Bos taurus* type milking cattle have only become established on islands in the Pacific and Indian oceans, in a small number of Caribbean countries and in a few specially favoured highland continental locations. An alternative policy adopted by some Southeast Asian countries endeavouring to develop a dairy industry is to import crossbreds. These are available in number from Australia and New Zealand and are mainly Sahiwal × Friesian crossbreds.

General Features of the System

Within this system cattle are triple-purpose. A cow is expected to work and milk during her lifetime and when she is too old to work, if social customs allow, she is sold for slaughter.

Feeding is often haphazard and management poor. Farmers do not usually understand the value of pasture and forages, but even if they did they do not normally farm a sufficient area of land (Table 7.8) to enable them to grow pasture or specialized forage crops for their animals.

Cattle are expected to graze or browse along the roadsides and irrigation bunds, and in the dry season on crop stubbles, otherwise they are tethered and fed cut forage and crop by-product feeds.

These farmers are, however, responsive to advice if they consider it sound and they are convinced that it will improve their standard of living. It is for this reason that in a number of countries it has been possible to convince them of the importance of milk production and the benefits that accrue if they become small commercial producers. They can only harvest these benefits when an organization for the collection and processing of liquid milk is established in their area. These organizations collect very small quantities of milk surplus to family requirements from a very large number of very small producers and process and channel it to urban consumers to the benefit of both rural and urban dwellers. India pioneered such schemes and has probably been the most successful in implementation. Many other tropical countries have attempted to copy the Indian projects, but not all have been successful.

The Development of Milk Collection Schemes

A milk collection scheme that has been very successful and has been built into a huge multimillion-dollar annual sales business is the Kaira District Cooperative Milk Producers Union Ltd in the Anand district of the State of Gujarat in India, some 400 km north of Bombay. The average size of farm in the area is 1.2 ha. The scheme commenced in 1946 when 112 small producers formed two village co-operatives. In 1949 the total collection of milk was 227 litres per day, in 1973 it was 772 810 litres per day. The latter volume was collected twice-daily from 344 000 cows managed in 800 village co-operatives. These co-operatives included 215 000 farming families, a total of approximately 1 million people, living in an area of 6475 km2. The milk supplied in this scheme comes almost entirely from buffalo cows, each family owning one or two, though some milking cattle are also utilized. The farmers bring their milk to the village collection centres in the morning and evening of each day, where it is tested for adulteration and for fat content. Payment for the milk supplied is made at the next collection and varies according to the fat content of the milk. The minimal standards required are 6.5% butterfat and 9.0% solids-not-fat. The average farmer delivers 3.6 litres of milk per day and retains approximately 30% of his total production for his family needs. The quality standard of milk delivered has steadily improved, approximately 3% being graded as sour. Sour milk is processed and used for the production of casein and ghee. All producers receive a uniform price for their milk, irrespective of the distance that their village is from Anand. The Union pays the cost of transport from the collecting centre to the processing plant and hires trucks for transport purposes.

The system of direct daily cash payments to the producers by the village societies is very popular and perhaps partly explains the success of the scheme. The village society is paid twice monthly by the Union. Approximately one-quarter to one-third of the proceeds from milk sales is used by the farmer to purchase concentrate feeds. Producers also receive a bonus once a year, paid from the profits made by their society. The village societies also use part of their profits to finance social schemes, such as the running of libraries and schools.

Perhaps most significant of all, this scheme has demonstrated how successful rural dairy co-operatives and milk-collection schemes can be in generating a development programme in the rural area of a poor country. The Union organizes AI units, mobile veterinary dispensaries, training schemes for all classes of workers, the largest livestock feed mill in India, credit facilities, an ear-tagging and milk-recording scheme, the prefabrication of cattle housing and extension work in many other fields.

In 195051 the AI service conducted 578 inseminations from five centres. In 1973 it owned a stud that possessed 60 tested buffalo breeding bulls and conducted 200 000 inseminations per year, there being one inseminator in each village. Partly as a consequence of better breeding practices, average production per buffalo cow improved by 50% between 1965 and 1973. The Union provided the services of 36 animal husbandrymen and 42 veterinarians in 1973. Veterinary clinics are held weekly in all villages and for a fee of US$1.80 the Union guaranteed (1973) that the service of a veterinarian would be available at any village within 4 hours.

In 1973 the Union was delivering 200 000 litres of milk per day to the City of Bombay for bottling and retailing through 2000 government-operated retail sale booths. The remaining 572 800 litres of milk were processed at Anand into milk products.

On account of the success of the Union, the National Dairy Development Board (NDDB) was established in 1965 and the 'Operation Flood' project conceived. In 1969 this project was approved by the World Food Programme (WFP). The concept was to create a flood of milk from the many small producers in the country-side to the consumers in the cities. This was to be accomplished by duplicating the Anand co-operative system of milk collection and processing around the four major metropolitan centres: Bombay, Calcutta, Delhi and Madras. The WFP donated 126 000 t of skim milk powder and 42 000 t of butter oil to the project and these were used to generate US$125 m that financed a modern dairy infrastructure. Operation Flood was in general very successful, with total milk procurement through the co-operatives rising from 0.46 to 3.1 million litres per day between 1970 and 1980.

Success generated demand for an even larger and more complex scheme. In 1977 the NDDB proposed that the original programme of Operation Flood should be extended to cover the majority of the major cities of India. This project, known as Operation Flood II was commenced with loan aid from the World Bank (US$140 m) and milk product aid from the European Economic Community (EEC).

These ambitious and generally successful projects in India have demonstrated the value of dairy development in the sedentary agricultural system, comprising many small and generally poor farmers and in some regions considerable numbers of landless labourers who may own one or two cattle or buffaloes. They have also demonstrated how the surplus dairy products of the developed world can be used to good effect by a developing country. On account of the development of the milk collecting and processing industry, commercial importation of whole and skim milk powder into India ceased in 1975 and the country is now self-sufficient.

Working Cattle

The spectacular success of some milk collecting and processing schemes has somewhat obscured the role of working cattle in this system. For example, Indian agriculture is still based on the plough with cattle contributing some 46% of the total energy required in the system, together with a large quantity of dung; almost 40% of the dung being used for cooking purposes and the remainder as a fertilizer.

The general consensus is that there is a shortage of working cattle in India, despite the fact that there are millions of half-starved animalsa situation widely condemned by Western-orientated livestock specialists. It can be argued, however, that Hindu beliefs and practices have assisted survival in a low-energy ecosystem. This is because:

- About 40% of the total cattle population are scavengers using less than 5% of the total grazing lands available.

- The poorest scavenger cows produce calves in years when there is a good monsoon and many are kept alive in years when there is a poor monsoon by religious Hindu organizations.

- Female calves from scavenger cows are frequently starved and die whilst male calves are raised for work purposes.

- All cattle produce manure, used either as a fuel or a fertilizer.

- Laws against slaughter discourage the sale of good animals during a drought; as Harris (1975) states, 'survival into old age of a number of absolutely useless animals during good times is the price that must be paid for protecting useful animals against slaughter during bad times'.

• Hindu religious laws discourage the growth of an energy wasteful beef industry, though some scavenging animals may be sold to Christians, Moslems and others for slaughter.

The situation with regard to the supply and availability of working cattle varies from country to country. Shortages experienced in India may continue despite improvements in the management and feeding of cattle that have resulted from Operation Flood and other projects. This could be on account of the crossbreeding programme that is targeted to produce superior milking cattle but not working cattle. In Southeast Asia cattle production has stagnated whilst mechanization has developed, producing some decline in the working cattle population.

It is in Africa that the number of working cattle is increasing rapidly, as everywhere sedentary cropping systems replace migratory systems, mechanization schemes have not fulfilled their original promise, and cultivation by working cattle replaces hand-hoe cultivation. In the Americas, the Caribbean region and in oceanic islands working cattle are gradually being replaced by tractors but the process is slow and not irreversible.

Further details on working cattle are provided in Chapter 21.

Meat Production

Old and culled cattle are slaughtered for meat in all regions with the exception of those in which there are religious taboos, but the present situation in Southeast Asia is of particular interest.

In the past, as the rural and urban populations of Southeast Asia slowly increased in number, demand for rice increased. In order to satisfy this demand new areas of land were brought into cultivation. Expansion of the cultivated area created an increased demand for work animals and ultimately provided increased supplies of beef. Thus the ratio of the human population to the cultivated rice area and to the total number of working cattle and buffaloes remained more or less constant, as did the ratio between the quantities of rice and beef that were produced.

Since the 1950s this equilibrium has been shattered. The urban population has expanded at an unprecedented rate, creating major increases in demand for rice and meat. The increased demand for rice has in large measure been satisfied, not by an increase in the cultivated area but by an increase in yield per unit area. The latter has become possible on account of the introduction of new agrarian technology, including new high-yielding cereal varieties, increased use of fertilizers, etc. The overall result has been that the working cattle and buffaloes population has not expanded at the same rates as the human population and rice production. The introduction of mechanization in the rice fields has further decreased the need for work animals.

Thus beef production per capita in Southeast Asia has fallen and urban populations have increased their consumption of pig and poultry meat. These changes are shown diagrammatically in Fig. 7.44. The inevitable result has been that the price of beef has risen more rapidly than the prices of other meat and of fish and that new systems of beef production have been stimulated.

As rice-growing systems are only seasonally labour intensive the farmers enjoy considerable leisure. As a consequence Southeast Asian farmers often participate in traditional cattle sports. These include bull-fighting in South Thailand and in some districts of Indonesia, and bull-racing on the island of Madura in Indonesia.

There are peasant economies in Southeast Asia where cattle and/or buffaloes are specifically raised for meat production. The system in Madura is particularly interesting. Madura, with an area of 4497 km2 and no pasture, supports approximately 570 000 head of cattle and buffaloes and 150 000 head of sheep and goats. An extraordinary livestock-carrying capacity of 1.3 large bovines per ha has been achieved by feeding the animals indoors on forage and browse cut from roadside grazings and trees. A major source of browse is the legume tree, *Sesbania grandifolia*.

Irrigation intensifies cropping systems and should therefore increase the demand for work animals. It also introduces the possibility of

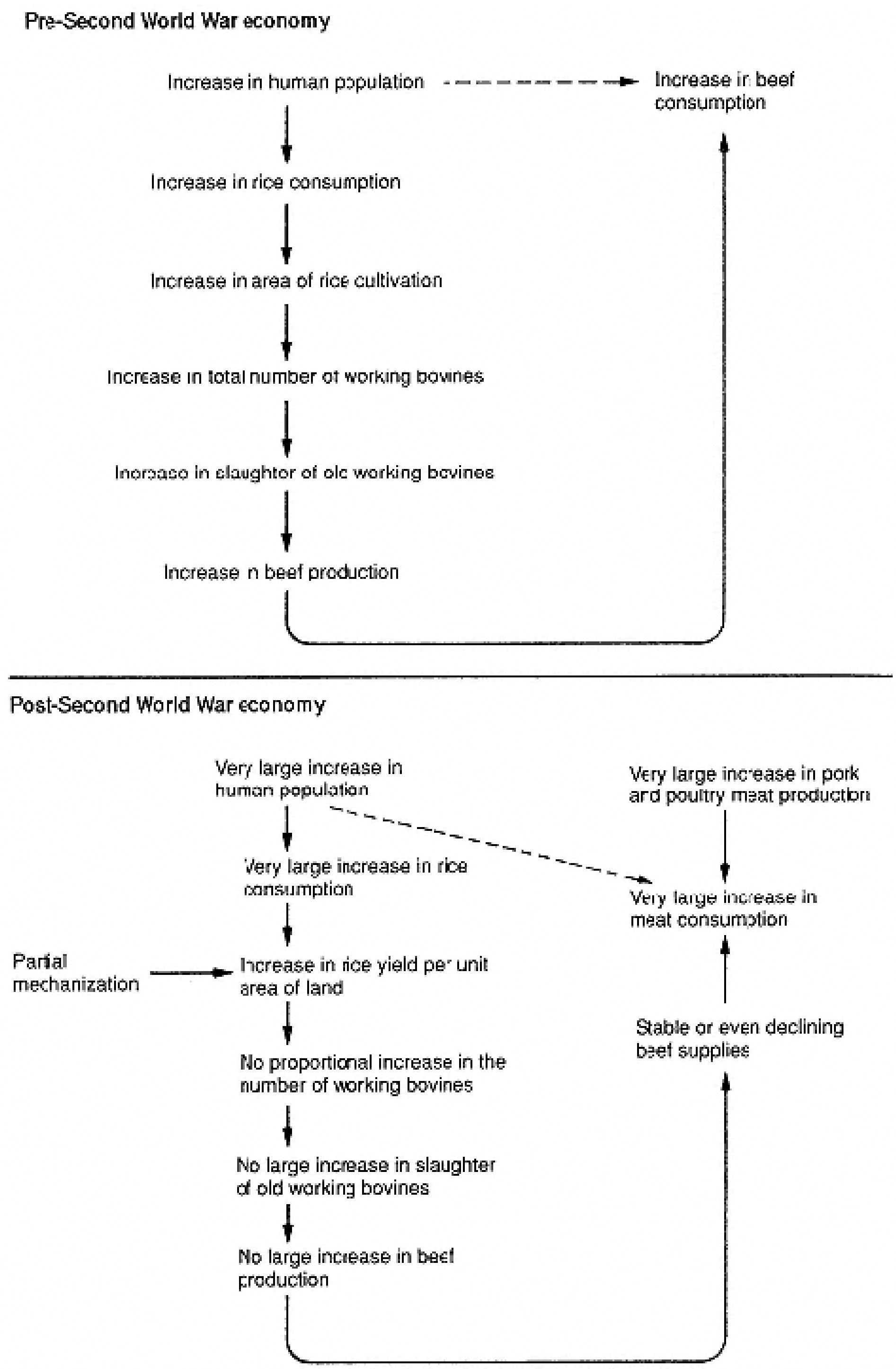


Fig. 7.44
The relationship between human population, rice production, working bovines and beef production in Southeast Asian sedentary agricultural systems.

providing forage on a year-round basis. In most tropical countries, however, irrigated land is too expensive to use for forage production. Irrigation has therefore often generated additional demand for work animals and at the same time aggravated the constant problem of obtaining sufficient feed supplies for them.

Problems of the System

The major problem is the small and continuously decreasing size of holdings. The development of sedentary cropping systems from more extensive systems has resulted from the pressure of population on limited land resources. Continual population increase results in a decrease in the size of holdings and ultimately in holdings that are too small to adequately support a family and the creation of a class of landless labourers.

Thus the solution in many regions is to decrease population pressure on land resources, halt the decline in the area of the average holding and find suitable cash and subsistence crops and husbandry methods in order to maximize production within the system. Decreasing population pressure on land resources requires political and social decisions and different countries have adopted or are adopting different solutions. These are outside the scope of this book.

A search for suitable crops and husbandry methods for small farmers is proceeding. As discussed above, milk is a very suitable cash crop for the small farmer, if collection processing and distribution can be organized in some collective manner. Other forms of intensive agriculture, such as fruit and vegetable growing, are also possible.

Intensive Systems.

Ley Farming

This is neither a major nor an expanding livestock system in the tropics. It is one in which temporary pastures are rotated with crops, whilst livestock utilize the pastures and crop by-products. Pastures are usually grazed for 3 to 5 years and then ploughed; the land being cropped for 35 years, before being resown to pasture species. Theoretically this is an excellent system for the tropics as it helps to prevent soil erosion, maintains fertility and produces a variety of cash crops and livestock feeds. There are, however, many practical difficulties. Ploughing grassland often requires heavy machinery and resowing pastures can be hazardous. Intensive research is required to ascertain suitable pasture mixtures and husbandry practices in each area.

The system is a temperate zone concept and on a large scale it has been introduced into the tropics by European settlers and achieved prominence in East and Central Africa. In the montane regions of East Africa wheat and pyrethrum cropping were combined with dairying or with the production of beef and/or mutton and wool. Intensive research was conducted at Kitale in Kenya on the most suitable grass and legume species to use in the pasture leys. On the tobacco farms of Zimbabwe and Zambia, pastures were rotated with the tobacco crop, primarily to control nematodes in the tobacco.

Ley farming, with concentration on dairying, has been widely advocated for smallholder settlement schemes, partly because it was successful on a large scale in the montane region of East Africa. However, ley farming has not generally proved to be a viable system in the lowland tropics. There are exceptions and rotation of crops and pastures, often 'tumble down' pastures on which livestock are grazed, has developed in some smallholder areas. Examples are: montane areas in Ethiopia where tef (*Eragrostis tef*) is cultivated, the montane region of Burundi, the Teso district of Uganda, the Serere district in Senegal and the Kano plains in Nigeria. There are also isolated areas of ley farming in tropical America, Caribbean countries and the Indian and Pacific oceanic islands.

An interesting experiment in lowland tropical ley farming in northeast Thailand is described by Gibson (1987). Two-year legume leys have been rotated with two years of crops (cassava, sugar cane and rozelle (*Hibiscus sabdariffa*, var. *altissima*)). The leys require phosphorus and sulphur fertilizers and are grazed by crossbred dairy cattle. Technically and economically a pilot

extension scheme has been successful, but complete acceptance by the whole farming community and spread of the system is not yet assured.

Limitations of Ley Farming

There appears to be considerable scope for the development of ley farming associated with semi-intensive beef and dairy production or mutton and wool production in the montane areas of the tropics. The system will, however, only develop if the farms are of a suitable size for mechanization and after intensive research has been conducted to determine productive grass and legume species for use in the ley seed mixtures, together with suitable husbandry practices.

The system is unlikely to develop in the humid, lowland tropics, where integrated perennial crop/livestock systems are increasing in number, but it may have some place in the drier but not the semi-arid lowland tropics.

Perennial Crop/Livestock Integrated Systems

Integration of livestock and crop production is not a new idea. Cattle have scavenged in fields after crops have been harvested since domestication first occurred; as they still do today in many countries. At other times livestock foraged in the woods, just as they do today in the rainforest of Southeast Asia and elsewhere.

What is perhaps new is the realization that crop/livestock integrated systems can improve productivity per unit area of land. This is important for, as previously stated, the population in many tropical countries is increasing very rapidly whilst the area of land available for agriculture is finite.

Three major integrated crop/livestock systems can be distinguished. These are: field crops in association with livestock (agropastoral systems), and tree crops in association with field crops, pasture and livestock (agro-sylvo-pastoral systems) or with pasture and livestock (sylvo-pastoral systems).

Bene *et al*. (1977) stated that half of all land in the tropics is suitable for agroforestry operations so that the possibility for increasing the number and scope of integrated systems is considerable. These systems are most likely to proliferate in regions where perennial field crops produce large quantities of by-product feeds, in the forest regions of the humid tropics where perennial tree crops have been replacing the indigenous forest cover, and in semi-arid regions where browse is the main form of forage.

Agropastoral Systems

Sugar cane, pineapple and sisal are crops with which livestock are already integrated to a greater or less extent.

Sugar cane provides three feed by-products: green tops, molasses and bagasse. Some interesting ideas on the use of these feeds in cattle nutrition are current. One is that whole sugar cane can be used either as a feed for cattle or for the extraction of sugar, depending on the market price of sugar. At first it was proposed that the cane should be peeled before feeding, but experience in the Caribbean and tropical America suggests that it is more economic to feed whole green cane in a chopped form. A second idea has been to add a non-protein nitrogen source, such as urea, together with essential minerals to molasses in order to produce supplements that may be used in the feeding of cattle; particularly during the dry season. Such feeds have found wide acceptance throughout the tropics. It has also been advocated that such mixtures can be fed to fattening beef cattle either in the feedlot or out on grazings, together with a protein feed of low solubility and high biological value and limited quantities of forage. This feeding regime has not, however, found wide acceptance as there are certain problems associated with it, such as the danger of urea poisoning. Bagasse is used to a limited extent, sometimes in the form of pellets, as a source of roughage in feedlot and other rations.

The processing of the sisal crop provides sisal waste that may be fed fresh or ensiled. This is a feed source that has not been widely exploited.

Cattle can also be used to graze between the sisal rows; acting as weeders.

Pineapples provide two feed by-products. The fruit processing waste from the factory may be fed fresh or ensiled or be dried to produce a pineapple bran. Immediately after the pineapple crop has been harvested cattle can be grazed across the fields to scavenge the large quantities of plant material that remain after harvesting.

Agro-Sylvo Pastoral and Sylvo-Pastoral Systems

As agro-sylvo pastoral systems are similar to sylvo-pastoral systems, except that in the latter systems grass is the crop, they will be discussed together. Three major types of system can be identified. These are:

• Grazing and/or browsing in natural forest.

• Grazing or harvesting forage grown under planted trees, including those used for the production of timber, firewood, nuts, fruit and industrial products, or combinations of these.

• Browsing and/or harvesting tree forage.

The Advantages and Disadvantages of Integrated Systems

As integrated systems have distinct and different characteristics in the wetter and the drier regions of the tropics, the situation in these two climatic environments will be considered separately.

The Wetter Regions

As cattle/tree crop systems simulate the rainforest ecosystem that they replace (Fig. 7.45) they have the following biological advantages:

• Available solar energy is used rather efficiently due to the vertical stratification of the vegetative components of the system.

• The soil is protected from severe erosion by two or more plant storeys.

• There is usually some vertical stratification of the root systems of the different plant species.

• The tree crop ensures some recycling of soil nutrients.

• If the trees are legumes and/or legumes are grown in the pasture mixture under the trees it

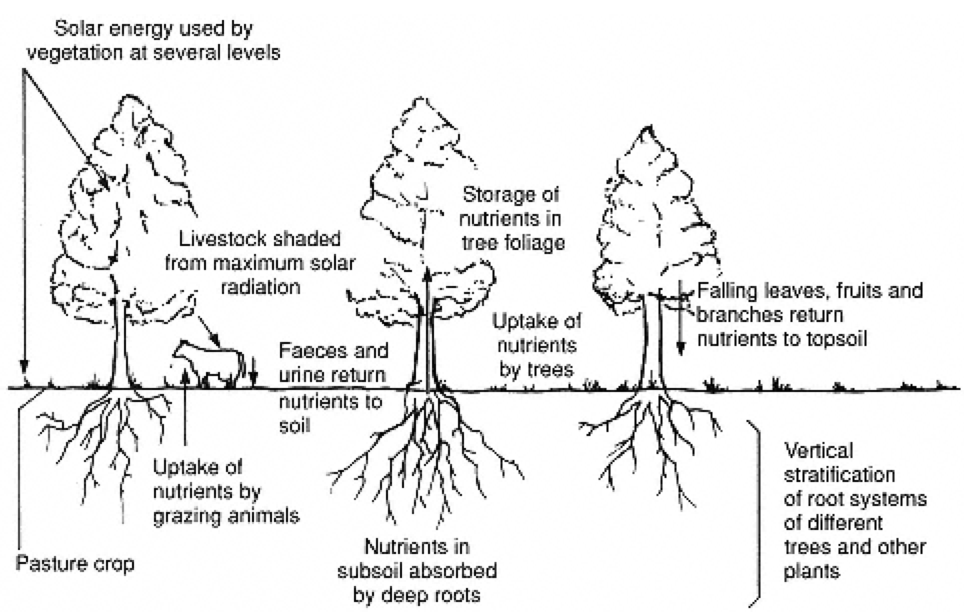


Fig. 7.45
Diagrammatic representation of components of a tree-crop/pasture/livestock system.

is possible to effect a long-term improvement in soil fertility.

There are also some possible economic advantages, such as:

- A reduction in the annual cost of weeding under the tree crop.
- A diversification of product output and labour input with a more effective utilization of labour on an annual basis.
- An increase in total product and revenue output per unit area of land.
- The chance of managing higher grade and therefore more productive cattle under tree crops, compared with using open grazing land in the same climatic environment.

If in the wetter tropics there are such obvious biological and economic advantages in integrating cattle with tree crops, the question must be asked as to why this is not the most common system employed. Particularly as very large areas of rainforest are being felled, especially in the American tropics, to establish extensive cattle ranches.

The main reason appears to be that integrated systems are managerially more complex than monocultural systems, with the following disadvantages:

- They require a higher standard of education on the part of the estate manager or farmer.
- Additional infrastructure and therefore capital per unit area is required.
- Difficult technical and techno-administrative problems have not yet been investigated.
- There is a general lack of practical experience in the management of these systems.

The Drier Regions

Dry forests have been traditional grazing areas since man first introduced domestic livestock. The systems used in these regions may possess many of the biological advantages discussed in the previous section, but they are located in rather fragile ecosystems, easily destroyed by a combination of fire and continuous overgrazing. They are essentially subsystems of pastoral systems so that the major problem in these regions is to stop and, if possible, reverse the degradation that is occurring.

Development of Integrated Systems.

Payne (1985) reviewed the possibilities for integrating cattle with tree crop production in both the wetter and drier regions of the tropics. These systems probably offer very considerable opportunities for the expansion of cattle production in the humid tropics. To date, the cattle/coconut system has been more completely researched and developed than any other integrated system and this will be briefly described as a possible model for the development of other cattle/tree crop systems.

Cattle/Coconut Systems

The Fats and Oil Team, FAO (1979) stated that the total area of coconuts in the world was approximately 7.2 million ha, of which 46% was planted in the Philippines and a total of 78% in Asia. Using this and other data, Payne (1985) estimated that the area of coconuts in the humid tropics suitable for cattle/coconut operations could be of the order of 6 million ha, but that at present some form of cattle/coconut production system is only used in one-sixth to one-quarter of this area. The possibility therefore exists for a very large expansion of coconut/cattle operations.

These systems may be easily established in those regions where total annual rainfall is 2000 mm or more, and is seasonally well distributed. Soils should be well drained. Tall coconut varieties should be planted at optimal spacing for maximum nut yield. Shade tolerant grass and legume species should be undersown. *Brachiaria brizantha*, *B. miliiformis* and some varieties of *Panicum maximum* appear to be suitable grasses and *Centrosema* *pubescens* is a legume used in many regions. Fertilizer application to palms and forage plants is usually essential in the long term.

Productive cattle should be rotationally grazed beneath the trees once these have grown to a sufficient height to escape damage from the animals. Adequate supplies of minerals and water should be available for the cattle. Stocking rates under good managerial conditions will vary from 1.5 to 3.0 livestock units per ha (Reynolds, 1977; Whiteman, 1977).

Other Systems

Cattle/oil palm, cattle/rubber and cattle/fruit tree crop systems are being developed, particularly in Southeast Asia. Details of such systems and others are provided by Payne (1985) and of cattle/coconut and cattle/oil palm systems by Wilson (1995). Integration of cattle and other livestock with timber trees is a system that has developed rapidly in the American tropics according to Budowski (1980) and is at present being researched in Oceania. The use of browse as a forage for cattle is widespread and the utilization of suitable browse species is under investigation in many tropical regions.

Modern Sector Cattle Production

There are two divisions of modern sector cattle production, dairying and intensive beef production.

Dairying

The specialized dairy farmer could become the most important milk producer in the tropics. There are today many sedentary crop agriculturalists with cattle who are rapidly developing into small specialist dairy producers. The size of the average holding, however, is a major obstacle to the organization of specialized milk production on any scale, and it is unlikely that large specialist producerscommon in the dairying areas of the temperate zonewill become an important factor in milk production in most tropical countries for some considerable time. Governments in some tropical countries are, however, funding specific projects and creating incentives in order to encourage the development of specialized dairy farms.

Examples of this type of development are to be found in Caribbean countries, where the schemes have been moderately successful, and to a lesser extent in Africa where in general the schemes have not been so successful. In Southeast and Eastern Asian countries, where milk is not a normal ingredient of the food culture and where there is no tradition of dairying. Western governments and the international development agencies have been invited to establish pilot-investigational dairy farms, around which it is hoped specialized dairy farming will develop. This type of project has been developed in Thailand, where a pilot-investigational farm funded by Denmark has, after some vicissitudes, been moderately successful. It is now the centre of a considerable dairying area and acts as a focus for a vigorous dairy extension programme.

If the evolution of partial subsistence farmers into small specialist dairy producers is to proceed rapidly it is essential for the authorities in each country to provide farmers with organized marketing facilities and efficient advisory and other auxiliary services. Central purchasing and milk-processing plants are required, together with advice on forage production, feeding, disease control and dairy hygiene, and loans for the purchase of the necessary equipment, buildings and stock.

The provision of an artificial insemination (AI) service could be most helpful to the small specialist producer. It could enable him to improve his breeding stock without the necessity of purchasing expensive bulls and allow him to keep an extra cow instead of a bull. The latter practice would increase his total production by a considerable fraction if he has only sufficient land to keep one or two mature cattle. There are, however, inherent difficulties in the establishment of AI services. Heat detection is often difficult in both exotic and indigenous dairy cattle in the tropics and communications are often very poor. Unless the service is well organized it may be very expensive for the government to operate and do little to assist the small farmer. For example, in one Asian country that one of the authors has visited the AI service was so inefficient and so expensive that it would have been more economic for the government to terminate it and give calves free of cost to small dairy farmers.

The Large-Scale Producer

There are a small number of large-scale private or government-owned dairy farms in most tropical countries. Even in India, there are many large government dairy farms, about 40 military dairy farms producing milk for the armed forces and others and some large-scale private farms.

Management, feeding and breeding practices on these large farms are usually superior to those on the smaller farms, not because they are inherently more efficient units, but because of the superior knowledge and resources of the operators. It is unusual, however, for the management of these large units to be of the same standard as that of the best dairy producers in the temperate zone.

The majority of the large producers manage their stock indoors, either in sheds or in yards. Some of them breed their own replacements, indeed many of them are breeding centres for the country in which they are situated, but others purchase replacement heifers. Where replacements are purchased, the culling rate is usually high, sometimes as high as 3050% per annum.

In a few regions of the tropics or the subtropics, there are either quite large-scale extensive-type dairy farms or moderate to large-scale beef ranches that produce milk.

The Atherton tableland in Queensland, Australia, is a region where large-scale extensive dairy farms are of some importance. The dairy farmers in this region practice seasonal breeding and normally make no effort to produce milk on a year-round basis. The milk that they produce is therefore relatively inexpensive and is mainly used for manufacturing purposes.

In some countries in Central America and in the northern countries of South America, such as Ecuador, Colombia, Venezuela and the northeastern states of Brazil, many extensive beef farmers select the best milkers in their beef-breeding herds each year and bring them into a milking herd that is managed adjacent to the headquarters of their holding. This is not a new practice, but it has been spreading as the demand for milk in urban centres has increased. It has many attractions for the smaller beef ranchers as it is a system that provides a regular weekly or monthly income, but it is also widely practised on larger ranches. Naturally, it can flourish only where both land and labour are relatively cheap and plentiful. The growth of this system has dictated some changes in the methods of breeding and management of the beef herds. It could be said that there has been a gradual intensification of overall managerial methods and an increasing use of dairy-type bulls in the breeding programmes. Brown Swiss bulls have been widely used and this has given some impetus towards the general utilization of dual-purpose-type cattle. In many of these Central and South American countries milk from the beef herds has become a major source of dairy products for the urban consumer, this milk often being transported over very long distances. For example, in Colombia milk produced in the Sinú valley in the northern coastal region is transported at least 450 km to consumers in the inland city of Medellín.

It is likely that the number of large-scale dairy farms in the tropics will slowly increase. They are unlikely, however, to supplant the small producers as the major suppliers of milk for a very long time, if ever.

The Most Suitable Milking Breeds to Use

There is of course no single breeding policy that is applicable in all tropical countries. Theoretically, specialized dairy farmers could choose one of four possible policies. These are:

(1) The utilization of indigenous cattle that are already well adapted to the environment, with selection for high productivity.

(2) The importation of highly productive, temperate-type cattle with selection for adaptability to a tropical environment.

(3) The importation of highly productive, temperate-type cattle and the management of

them so that the adverse effects of the tropical environment are ameliorated.

(4) The importation of highly productive, temperate-type bulls and/or semen for use in upgrading less productive indigenous cattle. This could be a continuing process or an effort could be made to 'stabilize' one or more specific crossbred types.

In practice, the farmer's choice is limited to the type of cattle that are already available in his country or to what cattle he can afford or is allowed to import. It is also limited by the scale of his operations, by the quality and availability of extension and other services and by his education and managerial skill.

In Asia and Africa, where there are many indigenous breeds, all except the largest producers or governments are likely to use those breeds that are readily available. During the last decades, breeders in many countries in Asia and Africa have attempted to improve the productivity of their indigenous cattle by selection and progeny testing, but the limitations on any improvement in the genetic merit of indigenous tropical breeds must be realized, as it is likely that some characteristics that ensure that these cattle are adapted to their environment adversely affect productivity. As Mahadevan (1966) stressed, with the exception of a few breeds average milk production of most indigenous tropical cattle is not much higher than 680 kg per lactation, so that their average genetic merit for milk production is low. In addition, the intensity of selection that can be practised is likely to be low for a variety of reasons, including long generation intervals and high mortality. Under these circumstances improvement in the milk production of indigenous cattle breeds is likely to be a very slow process. These general conclusions are reinforced by data published by McDowell (1971). He assembled information concerning four tropical breeds: the Blanco Orejinegro and Costeño con Cuernos in Colombia, the Abyssinian Shorthorned Zebu (Horo) in Ethiopia, and the Hariana in India. He found that the large numbers of non-lactating females present in herds of these breeds caused low herd efficiency (number in milk/total herd ×100). The herd efficiency percentages being 15.3, 19.6 and 26.5% for Blano Orejinegro, Horo and Hariana, respectively, compared with 58.8% for Holsteins in the state of New York. He also showed that on account of low herd efficiency, the supply of daily feed energy for the maintenance and production of Hariana cattle, producing on average 700 kg of milk per day, would be approximately four times that of cows producing at a similar level in a herd in the state of New York, and that only 11.5% of the estimated feed energy provided for the Hariana cattle was used directly for production as compared with 43.8% for herds in the state of New York.U

Even if the majority of indigenous tropical breeds are unlikely to provide very productive milking cattle and are at present without apparent economic utility, every effort should be made to preserve representative herds. This is a task that can be undertaken only by governments in most tropical countries.

Dairy farmers in some regions of Australia, the South Pacific and the Caribbean are in totally different situations from those in Africa and Asia. There were no cattle in these regions before settlement by Europeans. This has had some advantages, as indigenous cattle are usually subject to a variety of tropical diseases and countries in the South Pacific and the Caribbean are often free from serious tropical disease. Temperate-type dairy stock have been, and still are being, introduced into these regions, and where feeding and management standards are relatively high the exotic cattle thrive reasonably well and are fairly productive. It has been found that there are wide variations in the ability of high-producing, temperate-type dairy stock to thrive in the tropics and that some individuals thrive very much better than others (Payne & Hancock, 1957). There is no doubt that after importation some degree of natural selection for adaptation takes place, ill-adapted individuals being more likely to die before they reproduce. Selection for production along conventional lines will also lead to selection for adaptability. The practical proof of this thesis is that there are today in Australia, the Pacific islands and the Caribbean a number of herds of temperate-type cattle that, although not yet fully acclimatized, produce as well as or better than the very best herds of indigenous tropical cattle in Asia or Africa (Table 7.9). The most common temperate-type breeds found in the tropics are the Holstein, Jersey and Brown Swiss. However, it is generally accepted that if temperate-type dairy cattle are to thrive at sea level or at moderate altitudes in the tropics, then standards of disease control, feeding and management must be very high. That temperate-type dairy cattle can be productive in a tropical environment is demonstrated by the fact that the average yield of two separate but large herds of Holstein cows at Serge Island Dairies Ltd in Jamaica was 2902 and 3556 litres per lactation in 1983. The yields of two Jamaica Hope herds managed on the same property were 3163 and 2952 litres per lactation in the same year.

The situation in tropical South America is different again. The indigenous or Criollo dairy cattle are of the *Bos taurus* type. They are the descendants of cattle that were imported more than 400 years ago from Iberia. Previous to their importation there were no indigenous cattle on this continent, so that although the environment is not completely free from tropical cattle diseases, it is relatively free compared with Asia and Africa. The Criollo breeds are not very productive and crossbreeding with exotic cattle has been widely practised.

Little attention has so far been given to the third policy outlined above. Perhaps it is significant that although the importation of temperate-type cattle into the tropics is now not generally recommended, the importation of temperate-type methods of management have been condoned if not encouraged. It could be that the importation of unsuitable temperate-type management practices have contributed in part to the failure to date to establish any large number of temperate-type cattle in the tropics. There are many methods by which the climatic environment could be ameliorated and not all of them need expensive equipment. For example, little has been done to integrate tree cropping with dairy farming although it is well known that the microclimatic environment in coconut groves is very different from the climatic environment in open pasture and much more suited to the management of temperate-type cattle. The least expensive ameliorative method would be to utilize the medium and higher altitude regions of the tropics for dairy farming. If the mean annual temperature at sea level is 26.7°C then it is 23.3°C at 619 m and 18.3°C at 1524 m altitude. Obviously, at altitudes above 610 m temperate-

Table 7.9 Average performance of groups of dairy cattle in the tropics (data from 48 herds managed at locations at less than 2000 m altitude). (*Source*: McDowell, 1972.)

Group	Number of records	Milk yield		Lactation length		Calving interval		Age at first calving	
		(kg)	%a	Days	%a	Days	%a	Months	%a
Indigenous									
Random sample	2338	631	21	190	57	400	92	41.8	134
Selected	1464	1444	49	278	83	437	101	42.4	135
Crossbreds: random sample									
One-quarter temperate type	431	633	21	158	47	393	91	40.5	129
One-half temperate type	990	1843	62	278	83	414	96	35.0	112
Three-quarters temperate type	210	2074	70	312	94	441	102	34.9	112
Seven-eighths temperate type	27	2323	78	295	89	430	99	37.8	121
Exotic temperate type	1273	2974	100	333	100	433	100	31.3	100

a Percentage of data for exotic temperate-type cattle.

type cattle thrive considerably better than they do at sea level and at altitudes above 1524 m the mean annual temperature is optimal for maximum productivity in dairy cattle.

The general consensus of opinion is that crossbred dairy cattle are likely to be most economic in those regions of the tropics where management and feeding practices can be slowly improved.

The effect of crossbreeding in increasing productivity is not mainly on account of any hybrid vigour that may be expressed, though there is some effect, but because the low productivity of indigenous tropical breeds can be very rapidly improved by upgrading them using highly productive temperate-type bulls and/or semen. The farmer in the tropics has a choice of two practical methods of using crossbreeding to improve the productivity of his dairy stock. He can upgrade and then at some stage of the upgrading procedure mate *inter se* or he can use a rotational method of crossbreeding. Whichever system is adopted there are many formidable difficulties involved in operating crossbreeding programmes and it would be desirable for governments to produce stabilized crossbred milking animals that could then be distributed in their dairying areas and used in the first place for upgrading indigenous cattle. A number of attempts have been made to produce new milking breeds for tropical environments, including the Mpwapwa in Tanzania, the Sunandini, Karan Fries and Karan Swiss in South Asia and the Australian Friesian Sahiwal and Australian Milking Zebu in Australia.

The decision as to whether to utilize low-producing but well-adapted indigenous breeds, high-producing but ill-adapted temperate breeds or crossbreds must depend on a variety of factors. One of the most important of these is the local level of managerial skill. When levels of managerial ability and education are low, then the most suitable dairy animals are likely to be the indigenous breeds. This is usually the situation with peasant producers, but there are countries in the tropical world where these producers are highly literate, such as Sri Lanka and the Philippines, and there are other countries such as Kenya where the extension services have been particularly well organized. In these countries it is likely that an upgraded or crossbred animal could be immediately used. This is policy in Kenya where the relatively unproductive Small East African Zebu has been upgraded using the Sahiwal.

Even in those countries where the majority of peasant producers are illiterate and where management is generally poor it should be possible to slowly upgrade indigenous cattle. Indeed, it should be the aim to upgrade the level of managerial ability of the farmers at the same time as their cattle are upgraded. This is now an acceptable policy in many tropical countries, including India.

It is obviously pertinent to ask what the most suitable level of crossbreeding is likely to be. McDowell (1972) has cited evidence, using data obtained from 48 herds managed at locations where the altitude is less than 2000 m and scattered throughout the tropical world, that the higher the percentage of temperate-type blood in dairy cattle the higher is the production, the longer the lactation, the earlier the age at first calving and the longer the calving interval (Table 7.9). The first three of these characteristics improve productivity and it would appear from McDowell's data that it is only reproductive efficiency that is poorer in temperate-type cattle. These conclusions of McDowell are at variance with the conclusions of some other investigators.

Amble & Jain (1967) compared the performance of different grades of crossbreed dairy cows on military farms in India and concluded that the most productive were those with 5062.5% *Bos taurus* genes. In Thailand, Madsen & Vinther (1975) showed that under exceptional managerial conditions milk production increased as the percentage of temperate-type genes in crossbreeds increased (Table 7.10), though reproductive efficiency as expressed in the length of calving interval declined and total mortality up to the first calving increased (Table 7.11). More recently in Brazil, Madalena (1981) compared six different Holstein-Friesian × Guzerá crossbred grades. He showed that in the relatively harsh Brazilian climatic environment the 50%

Table 7.10 The effect of the percentage of *Bos taurus* genes on the length of the first calving interval and second lactation yields of dairy cattle in Thailand. (*Source*: Madsen & Vinther, 1975.)

Percentage of *Bos taurus* genes	Breed type: foundation females	Number	Length of first calving interval (days)	Second lactation yield (kg) Milk	Butterfat
0	RS and S	36	462	1000 ± 154	43.04 ± 7.18
37.5	T or T1	7	341	1193 ± 391	57.21 ± 14.83
50	T	83	383	1411 ± 114	72.96 ± 5.29
50	T1	107	391	1608 ± 106	78.70 ± 4.91
50	RS and S	18	384	2255 ± 197	101.60 ± 9.18
62.5	T or T1	54	396	1722 ± 135	77.45 ± 6.28
75	T	72	411	1996 ± 115	91.57 ± 5.36
75	T1	156	408	2210 ± 95	99.89 ± 4.42
87.5	T or T1	53	404	2238 ± 130	97.39 ± 6.05
100	RD (T)	17	577	2760 ± 200	114.50 ± 9.31
100	RD (D)	51	544	2561 ± 199	106.98 ± 9.23

RS = Red Sindhi; S = Sahiwal; T = Thai; T1 = Thai improved; RD (T) = Red Danish born in Thailand; RD (D) = Red Danish born in Denmark.

Table 7.11 Effect of percentage of *Bos taurus* genes on the mortality of female dairy cattle up to first calving in Thailand. (*Source*: Madsen & Vinther, 1975.)

Percentage *Bos taurus* genes	Foundation female type	No. heifer calves	Percentage mortality to 6 months	No. replacement heifers	Percentage mortality 6 months to first calving
0	RS and S	58	15.5	37	5.4
37.5	T and T1	450	9.1	243	10.7
50	T	209	3.3	208	2.9
	T1	183	3.3	181	1.7
	RS and S	85	5.9	53	0
62.5	T and T1	251	8.8	146	9.6
75	T	196	7.7	165	7.3
	T1	438	7.3	364	9.9
87.5	T and T1	152	9.2	130	20.0
100	RD	96	7.3	93	23.7

RS = Red Sindhi; S = Sahiwal; T = indigenous Thai; T1 = improved indigenous Thai; RD = Red Danish.

Bos taurus × *Bos indicus* grades were the more productive without loosing adaptability and suffering high mortality. Cunningham & Syrstad (1987) studied the results of 30 crossbreeding experiments conducted in the tropics involving Friesian, Jersey, Red Dane, Brown Swiss, Ayrshire, and Dairy Shorthorn *Bos taurus* breeds. They concluded that the performance of crossbreeds improved up to the 50% *Bos taurus* level, but that above this level the results were very variable and often disappointing. Vaccaro (1990) studying the use of purebred temperate-type cows in the South American tropics and subtropics came to the conclusion that they suffered from an unacceptably high mortality and were not a viable option for dairy farmers.

In the opinion of the authors the answer to the question as to what is the most suitable level of crossbreeding depends upon the geographical location of the site at which it is conducted, the availability of suitable feeds, the local incidence of disease and parasites and the level of managerial skill available. What is interesting about the data of McDowell (1972) and Madsen & Vinther (1975) is that they suggest that it is possible to manage high-grade, highly productive dairy cattle in the tropics but the experience of the authors is that this can be accomplished only under very exceptional circumstances. One author worked in the south Pacific where there are examples of pure and high-grade *Bos taurus* type dairy cattle producing reasonable milk yields under tropical conditions. The circumstances are, however, exceptional. Disease is limited, feed availablity high throughout the year and management probably above average for tropical countries.

Despite the exceptions cited above the authors consider that the available evidence suggests that, unless they are managed in a closely controlled environment, it is very doubtful whether purebred or high-grade dairy cattle should be used in most regions of tropical Africa, the Americas and Asia. Where management is of a fair standard but endemic diseases are prevalent and/or feed resources are very seasonal, the authors believe that the use of no more than halfbred (*Bos taurus* × *Bos indicus*) is indicated, a conclusion reached by Payne & Hodges (1997). If, however, disease is under control and feeding conditions are good the use of higher-grade crossbred milking cattle might be justified. The experience of one of the authors and data from Thailand (Madsen & Vinther, 1975) suggest, however, that although production can usually be improved by the use of somewhat higher than 50% grade cattle, the offspring tend to suffer from a number of minor troubles that complicate management and disease can be troublesome and expensive to mitigate, even when the management is exceptional.

When governments or large producers organize crossbreeding programmes, then, it must be most desirable to upgrade using the best possible temperate-type bulls or semen, as the higher the genetic merit from a productivity point of view, the lower the level of temperate-type blood that has to be introduced in order to attain a reasonable level of productivity in the crossbreds. As it is easier to obtain bulls and semen of high genetic merit from the major rather than from the minor temperate-type dairy breeds, and the production of beef from the dairy herd is of importance in the tropics, the breed of choice for upgrading indigenous cattle should probably be the Holstein. All European breeds, however, combine satisfactorily with indigenous tropical breeds.

Brown Swiss also possess many of the desirable features of the Holstein and the breed has been widely used in crossbreeding programmes in Latin America, but the overall use of this breed is probably declining due to the relative unavailability of sires of high genetic merit.

If it is decided to import purebred temperate-type stock there does not appear to be any advantage in importing pedigree cattle. Probably the most suitable policy is to import good-quality-grade heifers and bulls and/or semen of the highest genetic merit.

Management and Feeding

It is proposed to discuss the management and feeding of the various classes of dairy cattle from the point of view of the specialized dairy producer, although it is recognized that at the present time small producers may not be able to apply all or even the majority of the practices discussed. The authors believe, however, that some or most of these methods can be gradually introduced on even the smallest farms in most tropical countries and that it is desirable that ultimately they should be so introduced.

The Calf

The first decision that a dairy farmer has to make is what calves he will rear. A breeder will raise almost all his heifer and bull calves, and sell the surplus as breeding stock. Commercial milk producers have a choice of several policies. If they raise single-purpose dairy animals, such as Jersey or Jamaica Hope, they will want to rear all their heifers but may wish to dispose of their surplus bull calves as soon as possible. In the past, in most temperate countries, these surplus bull calves would have been slaughtered and the meat used for manufacturing purposes. Now, most surplus bull calves are reared for beef production. In some tropical countries there is a local market for surplus, live, young calves. For example, in the island of Madura in Indonesia large numbers of young calves are sold in the markets from 6 weeks of age.

If the farmer raises dual-purpose cattle, and this is normal in the tropics as most tropical breeds are dual- or triple-purpose, he can keep all his surplus bull calves and raise them to sell as bulls or steers, either for meat or for work purposes. There is also a third policy that is not widely practised in the tropics. The farmer can keep a beef or work-type bull and use him to serve the poorest producers in the herd, only using the better cows for breeding future dairy replacements. The crossbred calves, both heifers and bulls, can then be raised for beef or work. This is a very desirable policy, but it cannot usually be practised because calf mortality is often high and the farmer needs all the dairy heifers that he can rear for replacements in his dairy herd.

Calf-Rearing Systems.

Calves can be reared indoors or outdoors, or partly indoors and partly outdoors. In cold temperate countries calves are often reared indoors for the first 6 to 9 months of life because of lack of grazing and the cold weather, but in warm temperate countries such as New Zealand calves are usually reared outdoors throughout the year.

In the humid tropics, where temperatures are high all the year round and grass growth is more or less continuous, it might be thought advantageous to follow the New Zealand practice of outdoor rearing. This is not necessarily so, however, for three reasons. First, it is difficult to keep the grass in calf paddocks in a young, palatable stage; tropical grasses grow and mature very quickly and at maturity possess a high lignin and low protein and mineral content and are not suitable for calf grazing. Secondly, a humid tropical environment is ideal for the proliferation of internal parasites and it is very difficult to keep the calves free from massive infection if they are grazing. Thirdly, even if the calf grazings are well shaded the calf is exposed to considerable climatic stress at a stage of life when it is least resistant. The combination of low nutrient content forage, parasites and climatic stress is inimical to calf life, and calves raised under these conditions usually have a high mortality rate.

There is, however, some experimental evidence from the Philippines (Payne *et al*., 1967) that suggests that where management of grazings and cattle is good, dairy calves in the humid tropics grow most rapidly when managed on an indooroutdoor system (Table 7.12). That is, outdoors at night and indoors during the day-time. Under this system the calves receive considerable protection from climatic stress, and it has been found that because the larvae of most internal parasites are phototropic they are more likely to be ingested by calves during daylight grazing than during grazing at night when the parasite larvae have moved down the stems of the forage towards the soil. Calves that are managed on an indooroutdoor system should never be kept in special calf paddocks but should be rotationally grazed at night on the normal grazings some days before the milking cows so that they can obtain the most nutritious of the available forage. They should not be grazed on poor pastures, and they should be fed indoors during very wet and/or stormy nights. The Philippine data showed that the liveweight gain of the calves was significantly better in the drenched, indooroutdoor-managed group. There was less mortality in the indoor-managed group, but the differences were not significant. Even allowing for the higher mortality, overall production was superior in the drenched, indooroutdoor-managed group. What was also significant was the very high (40%) mortality in the undrenched, outdoor-managed group. Of course it is not always possible in some tropical countries to manage calves out of doors at night on account of the activities of human and/or animal predators.

In the arid tropics, the risk of parasitism is less than in the humid tropics, particularly during the dry season, but grass growth is very seasonal and during long periods of the year no suitable grazing is available for calves. They may be reared on an indooroutdoor system during the period of

Table 7.12 Effect of management and drenching with a vermifuge on liveweight gain and mortality in dairy calves at Los Baños, Philippines. (*Source*: Payne *et al*., 1967.)

Group	No. calves	Liveweight gain (kg per day)	Percentage total mortality
I Indoor management	28	0.344	3.6
Drenched	15	0.385	6.7
Undrenched	13	0.300	0.0
II Indooroutdoor management	23	0.404	8.7
Drenched	10	0.435	10.0
Undrenched	13	0.380	7.7
III Outdoor management	27	0.387	29.6
Drenched	12	0.403	16.7
Undrenched	15	0.369	40.0

(1) The calves were mixed Sindhi × Friesian crossbreds and high-grade Friesian.
(2) The experimental period was from 13 to 52 weeks of age.
(3) Calves were selected for the groups at random.
(4) Thiabenzole, phenothiazine and promintic were used alternatively as vermifuges for two-thirds of the experiment; during the latter third only thiabenzole was used. Drenching was at 14-day intervals.

rapid grass growth, but as in the wet tropics they should not be reared in special paddocks. During the dry season it is likely that they are best reared indoors.

The most practical indoor-rearing system is one in which the calves are reared in a calf shed sited in an earth or gravel yard where they may exercise. The essentials of a good calf house (Fig. 7.46) are that it should provide adequate shelter, should be easily cleaned, and should keep the young calves warm in cool weather and cool in warm weather. It may be no more than a simple roof over a concrete base on a well drained site. The roof should be at least 3 m in height at the eaves. Side walls are not necessary in the humid tropics as long as the roof has a wide overhang to keep out driving rain. No additional shade is required in the yard as the calves can shelter under the overhang of the roof or in the pens. Under the roof, provision should be made for individual feeding, separate pens, etc. Tubular steel is the most suitable material from which to construct individual calf ties, though hard timber or bamboo will suffice.

The yard must be kept free from all vegetation in order to reduce parasitism. The calves should have access to water, preferably under the shade of the roof, concentrates, good-quality forage and minerals. They should have a dry bed on which to lie, and are best bedded down on straw or sawdust, though this is not essential. It is usual to rear and feed the calves individually for the first few weeks of life and thereafter in batches. The internal layout of the type of calf shed described can easily be altered to suit particular circumstances. In some tropical countries individual calves are raised for the first few weeks of life in a special calf pen that is raised off the ground and possesses a slatted floor through which the faeces and urine drop (Fig. 7.47). The following conditions should be observed in its construction:

(1) The slats can be made of metal or wood and should be spaced at appropriate intervals.

(2) The sides of the pen should be as open as is possible so that air can circulate freely.

(3) The pen should be sited on a sloping floor so that faeces and urine can be easily removed. Raising the pen

above the floor also assists air circulation and cooling.

(4) Water, concentrate and mineral containers can be attached to the walls of the pen at appropriate locations.

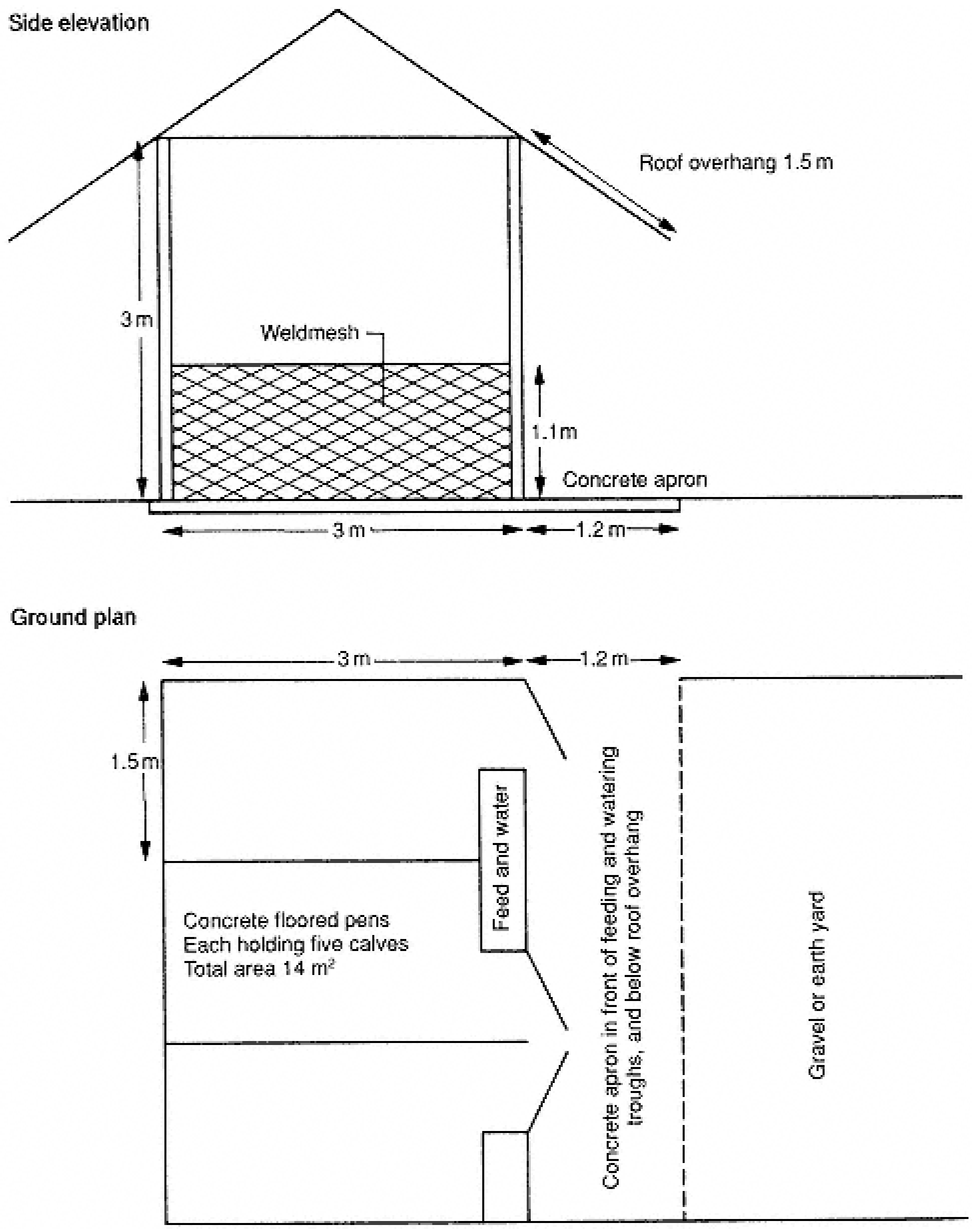


Fig. 7.46
Plan of a simple calf house suitable for a humid tropical environment.

This is a good system, but it is more costly and not essential if conventional calf pens are cleaned daily and kept dry.

Calves that are running in batches often suckle or lick each other after feeding and it is a good practice to keep them in their ties for some time after milk feeding. Hair swallowed by the calves after suckling each other often forms a hard ball in the abomasum and this is a constant cause of digestive disturbances.

If for any reason dairy calves have to be reared entirely outdoors in the tropics, as stated above

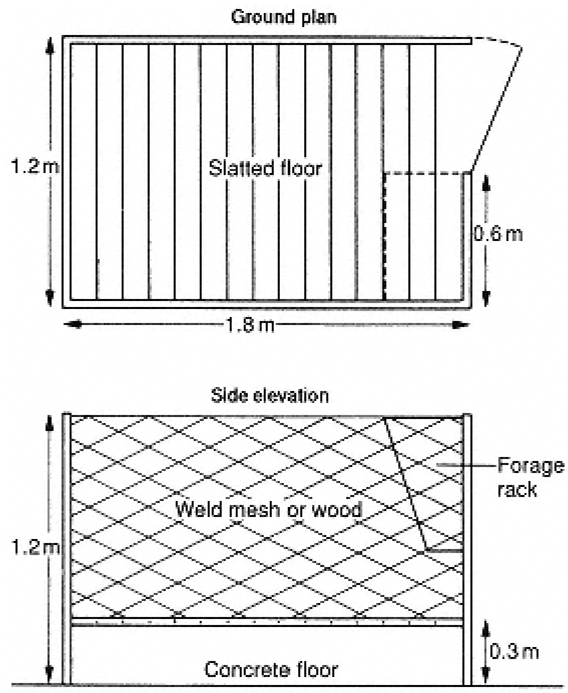


Fig. 7.47
Plans of an individual slatted-floor pen for a young calf.

they should not be reared in special calf paddocks but be rotated round the milking cow grazings. It has been found in New Zealand that the best system is to rotate the calves around the grazings at least 10 days ahead of the dairy herd. In order to practise this system, the farmer needs at least 1420 separate paddocks.

Whether calves are reared indoors, outdoors or on an indooroutdoor system it is usual to bring them to one central point to feed milk and concentrates, as it is easier to walk the calves to the food than to bring the food to the calves.

Feeding

The digestive tract of a young calf differs from that of a mature cow and the calf does not function as a ruminant until it is a few weeks old. In the calf the capacity of the true stomach or abomasum is 70% of all four stomachs, whereas in the mature cow it is only 7%. When the calf suckles, the milk bypasses the rumen and reticulum and passes directly into the true stomach or abomasum (Fig. 7.48), and only if the calf

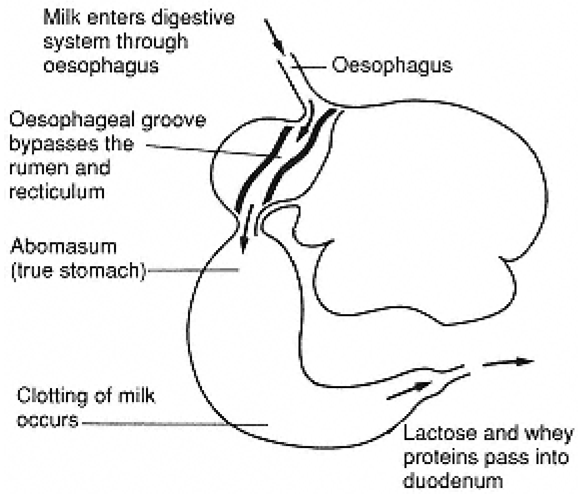


Fig. 7.48
Diagrammatic representation of the digestive system of the very young calf.

drinks too much does any milk pass into the rumen. The stimulus for the activation of the oesophageal groove 'bypass' is the presence of fluid in the back of the mouth. Milk going into the rumen of a small calf may curdle and then, because rumination has not yet commenced, putrefy, causing digestive disturbances. Thus it is a better practice to feed the calf small quantities of milk at frequent intervals than large amounts at infrequent intervals. Suckled calves running with their mothers are least likely to suffer from digestive disturbances as they suckle frequently. This is the method by which beef calves are raised, but in the past it has not usually been considered practical or economic to raise dairy calves in this way. There are authorities who now advocate the suckling of calves after twice-daily conventional milking for a period of 4 weeks and then after one milking only for a further period of 6 weeks. It is stated that this practice does not decrease overall milk production and that it improves the growth and health of the calf. There is also one other benefit; the incidence of mastitis is reduced in the milking cows. Alternatively, dairy calves can be suckled by raising them on a nurse cowone, two or three calves being raised according to the milk yield of the nurse cow. This is quite a common practice among breeders of dairy cattle and could be a desirable practice in the tropics where calf mortality is high and general feeding and management practice are poor. Old cows and cows with 'blind' quarters may be used for this purpose.

The majority of peasant farmers in the tropics allow the calf to suckle before milking in order to obtain a let-down of milk. There are many variations of this practice. The most common is for the calves to be shut away from their dams during the night while both cows and calves are held in separate enclosures. In the morning a calf is brought to her dam before milking commences and allowed to suckle for a short while, then the calf is taken away and the milker commences milking. Sometimes, as for instance among many of the nomadic tribes in the savanna regions of Africa, the calf is not taken away completely from the dam, but is held by a ropeusually controlled by a childin front of her dam, who licks the calf while milking proceeds. Other people allow the calf to suckle the front or back teats while they take milk from the remaining teats. Yet others allow the calf to suckle on the one side while they take milk from the other pair of teats. All these peoples insist that their cows will not let down their milk unless the calf has first suckled; and in the past many authorities have reiterated that cattle of indigenous tropical breeds, particularly the zebu breeds, act in this manner. The practice is undesirable as it is both uneconomic and unhygienic and it can be stated quite categorically that it is not absolutely essential to suckle the calf of any breed in order to induce the dam to let down her milk. What in fact happens is that a vicious circle is created. The farmer starts the heifer off in this way at first milking and then claims that his cows will not let down their milk unless they are first suckled. If heifers are milked by hand without suckling some of them will let down their milk. Those that will not should be culled at the end of the first lactation. In this manner it is possible to build up a herd of dairy cattle of any breed that will let down their milk without the calves first suckling. There is, for example, a Sahiwal herd of approximately 500 breeding cows at Naivasha in Kenya that in the 1960s was milked with the calves afoot; in 1973 all the cows were milked without pre-suckling and the average yield was 1630 kg per lactation.

If the calf is not suckled but bucket fedthis being the normal practice in dairy farming countriesthen it is better to bucket feed three or more times a day for at least the first 2 or 3 weeks. Many farmers bucket feed through a nipple as this slows down the rate of feeding. The disadvantage, in the tropics, of bucket feeding through a nipple is that the practice requires more equipment, and that all this additional equipment has to be kept very clean, thus adding to the expense and the difficulties of management, particularly where no piped water supply is available.

Whether the calf is to be suckled or bucket fed it is essential that it should receive the colostrum or first milk from its mother. It should be fed its mother's colostrum for 3 days, but if it is to be bucket fed it should be allowed to suckle its mother for only the first 1224 hours, and after that her colostrum should be fed from the pail.

Colostrum contains twice as much dry matter as milk. The protein content can be up to 18% as against 35% in most milks and it is of a different quality. Colostrum contains very much larger quantities of vitamins and minerals and it is also rather laxative and helps to clear the intestine of the young calf of accumulated faecal material. It also contains antibodies needed by the growing calf. These assist the young calf to protect itself against disease. It is particularly important that the young calf should get colostrum within the first 24 hours after birth as its digestive tract can absorb the antibodies during this period, whereas later they cannot be easily absorbed. Surplus colostrum may be fed to the older calves. It is usual to mix it with milk or with water, but this is not essential.

It is sometimes difficult to start a calf drinking from the bucket. The usual method is to starve it for a few hours and then place a hand in its mouth when feeding so that the colostrum laps against the mouth and the calf sucks it up through the fingers, which are then gently withdrawn. The young calf often 'bunts' while being bucket fed; this is quite normal as this is how it starts the 'let-down' of milk in its mother, but it means that the feeding bucket must be secured in some way otherwise the calf will spill its food.

The calf cannot use average-quality tropical roughage extensively until it is 3 or 4 months old and if it is weaned early and fed solely on roughage its growth will be slow. Consequently, it is desirable that calves should be suckled or bucket fed milk and/or a milk starter for as long a period as is economically practical and also fed concentrates and as high a quality roughage as is obtainable. Legume browse roughage is particularly desirable as it can be highly nutritious.

Suckled calves, if raised outdoors, may select what grass they need, but indoors they are usually fed concentrates and cut forage. Bucket-fed calves are usually fed whole milk for a short time, then a whole-milk substitute or skim-milk and finally they are weaned when about 36 months old. During this period they should also have access to concentrates and cut forage. The 45 kg calf requires food with a nutritive ratio of about 1:4, but as it grows it can gradually deal with foods with a higher nutritive ratio.

Early weaning is now practised extensively in temperate-zone countries. Calves are introduced to specially prepared calf starters when they are 10 days old and to good-quality roughage as soon as possible. They are weaned, either abruptly when about 24 days old, after being fed 2.7 kg of whole milk daily, or gradually when they are given 2.7 kg until 10 days old and thereafter 0.5 kg less each week until milk feeding is stopped when the calf is 31 days old. When thus weaned their growth is severely checked, but in due course they recover satisfactorily and apparently suffer no permanent damage. It is necessary to compromise between the needs of the calf and the cost of rearing. In the tropics where conditions are less favourable to the calf it is probably more economic to feed the calf additional whole milk than to attempt to early wean and raise it on the minimum quantity. There are obviously all types of compromise managerial systems between early and late weaning. The choice of system must depend on local circumstances. For example, in the Sahiwal herd in Kenya cited above, the calves were reared on whole milk until they were 9 weeks of age. The possibility also exists of bucket rearing calves on specially prepared synthetic milks, particularly those prepared from soybean products. These types of milk could be cheaper than cows' milk and of particular utility in the tropics.

It is usual to ration the calf to 1012% of its own body weight of milk a day. Some authorities advocate the feeding of up to 15% of the body weight of milk daily, but this is not general and certainly should not be practised in the tropics where calves usually grow more slowly than they do in the temperate zone. The milk should be warmed to body temperature and the calf should be fed three times daily during the first week, if that is practicable.

Although it is preferable to first feed a calf whole milk and then skim-milk, this is normally an uneconomic practice, and in the temperate zone milk substitutes are used in place of whole milk from about the second or third week of life. The quantity of milk fed daily is reduced and by the fourth week only milk substitute is fed. Bucket feeding may be discontinued as the calves grow older and they may be collectively fed, using clean, glazed earthenware troughs. In the temperate zone automatic dispensers of milk substitute are being employed and these machines have some advantage, as apart from reducing the cost of labour they ensure that the milk supply is always available and at the correct temperature.

A decision as to whether to feed whole milk for a longer period, skim-milk or milk substitutes must depend on local circumstance. In a dairying area where ghee or butter is produced, skim-milk may be available in quantity, and milk substitutes are becoming increasingly available in the tropics as livestock feed industries develop. What must be remembered is that, in general, the environment in most tropical countries is more disadvantageous for the dairy calf than it is in temperate-zone countries and that it may be economic to spend additional money on calf rearing in order to reduce calf mortality and increase calf liveweight gain. It must also be remembered that most dairy calves in the tropics, whether from *Bos indicus* or *B. taurus* breeds, are smaller at birth and grow somewhat more slowly than would similar calves in the temperate zone. Thus temperate-zone feeding standards are not completely applicable in the tropics and if adhered to are likely to lead to some overfeeding of the calves.

Average tropical dairy calves probably weigh 2027 kg at birth and during the first week they should be fed no more than 2.8 kg of milk a day. By the fourth week this could be raised to 3.7 kg of whole milk or milk substitute per day. Heavier calves should of course receive correspondingly larger quantities. It is likely that the amount of whole milk or milk substitute fed should never exceed 4.5 kg per day as the calves will begin to eat concentrates and forage in increasing amounts as they grow older. Some farmers dilute the milk or milk substitute that they feed to their calves, but this is not necessary.

Although milk is essential for young calves they must also be fed other foods. Calves fed only milk may suffer eventually from magnesium deficiency, and die.

Calves, however fed, should have access to concentrates from 23 weeks of age and to the best-quality forage available. The type of concentrate that can be fed obviously depends upon what is locally available. A suitable mixture of feeds that is likely to be available in the wetter tropics is:

Coconut meal	50 parts
Groundnut meal	25 parts
Maize meal	25 parts

The following mixture for calf rearing has been recommended in India:

Wheat bran	30 parts
Linseed cake	10 parts
Barley meal	20 parts
Jowar (*Sorghum* spp.) meal	20 parts
Maize meal	20 parts

At 2 months of age average calves in the tropics will eat up to 0.45 kg of concentrates per day, and at 3 months of age at least 0.7 kg per day. If the calves are weaned after 3 months, and are well grown, they will soon eat 1.41.8 kg of concentrates a day as well as forage.

When calves are fed indoors special precautions must be taken to see that they receive adequate amounts of minerals and vitamins. If a commercial vitamin-mineral premix is not availableas it may not be in some tropical countriesit is best to add a little fish-liver oil to the diet and to make available a mineral mixture. The mineral mixture may be fed with the concentrates.

Calves should always have access to water. It is a mistake to assume that they do not require water because they are being fed large amounts of milk or milk substitute.

Special Managerial Considerations

When a dairy cow is about to calve she should be brought to a place where she can be kept under observation. Some farmers provide special calving pens, but this is not essential unless contagious disease is endemic. Occasionally a cow needs assistance at calving, especially when a tropical-type cow is delivering a crossbred calf got by a temperate-type bull, but help should be given only when it is absolutely essential. After birth the cow will clean the calf by licking it.

Most breeds of dairy cattle are horned and horns are a disadvantage in dairy operations, though the farmer may wish to retain them on bull calves to be raised for work or on dual- or triple-purpose heifer calves. Dehorning is best done by cauterizing the horn bud when the calf is a week or two old, either by rubbing the bud with a caustic stick till it is near bleeding, by the use of collodion, or by the use of a cylindrical red-hot iron pressed for a second or two on the rim of the horn bud. The latter operation is usually carried out at 34 weeks of age. If electricity is available an electric hot iron is most effective. When a caustic stick is used care must be taken that the calf does not carry the caustic to the cowin suckling for instanceand that the caustic does not spread from the site of the operation, particularly into the eyes. This may occur if the calf is exposed to rain soon after application of the caustic stick.

Castration can be carried out with a knife, with crushers, or with a rubber ring. The rubber ring method is the most suitable for calves up to 2 or 3 weeks old. When the operation is performed by this method on calves that are about 10 days old it causes a minimum of pain or discomfort. The Burdizzo bloodless castrator makes the operation a comparatively safe one at all ages.

It is desirable that calves should be marked at as early an age as possible by one of the methods referred to in Appendix I. If the dairy herd is recorded it is essential that the calves should be marked.

Calf Mortality and Disease

Dairy calf mortality in the tropics is undoubtedly very high. Often it is as high as 50%, but this almost invariably denotes bad management. In some areas a high death rate is partly due to the fact that unacclimatized temperate or crossbred stock are used for dairying and climatic stress is added to the other hazards of calf life, but it is more usually due to poor feeding and faulty management. It is a truism to say that the best way to reduce calf mortality is to practise good husbandry. Some common ailments can be treated by the farmer, but once the calf is seriously ill or large numbers of calves are ill, expert veterinary advice should be sought.

The most common disease of calves is 'scouring'. The usual symptoms are a dull appearance of the eyes, listlessness, diarrhoea and sometimes an abnormal rise in temperature and respiration rate. Scouring may be due to purely mechanical causes, nutritive causes or to infection. Calves that drink too rapidly, are fed cold milk or have hair balls in their abomasum, often scour. Treatment consists of starving the calf for 24 hours and then feeding small quantities of milk diluted with a little water that has been heated to body temperature. Calves suffering from this type of scour usually recover if treated properly. Scours caused by infection are usually more serious both because there is greater danger of death of the infected individual and because a large proportion of the calves are usually affected. The faeces are often a chalky-white colour and have a very offensive smell. Infection may enter through the mouth, but sometimes enters through the navel cord. Often the calves die within a very short time. The use of antibiotics in the feed of calves undoubtedly reduces the incidence of scours caused by infection but in the long term could be an undesireable management practice.

Pneumonia often occurs when a calf is suffering from scours. The symptoms are as follows: the temperature rises rapidly, the respiration rate increases and the calf 'gasps' for breath. The primary cause is almost invariably an infection predisposed by sudden changes in the environmental temperature and humidity.

The young calf is particularly vulnerable to attack by internal parasites. Calves suffer from roundworms, threadworms, hookworms, lungworms, tapeworms, coccidia and other internal parasites. Symptoms of parasite attack are a 'falling back in condition', a dry rough coat, a pot belly and a swelling under the jaw. Internal parasites are best controlled by good calf-house hygiene, proper rotational grazing and a systematic drenching policy. In the wet tropics it may be necessary to drench the calves at very regular and comparatively short intervals; in the drier tropics it may only be necessary to drench the calves at certain seasons of the year.

The Heifer

The rearing period of the heifer from weaning to first calving divides naturally into two stages: one from weaning to first service and the other from first service to calving.

The aim in rearing heifers should be to achieve the maximum growth and development and the earliest sexual maturity consistent with least cost. This ensures that maintenance costs are minimized, that there is the earliest possible return on the investment in the original animal and that the heifer probably produces well during her first lactation.

There is always some check to growth at weaning. If the heifer calf is being rotationally grazed on nutritious pasture, either on an outdoor or and indooroutdoor system of management, the check will be minimal. However, if she is being raised indoors and is abruptly weaned and suddenly placed outdoors on indifferent-quality pasture, the growth check will be very severe. Although it is now well established that short periods of retarded growth, resulting from suboptimal feeding, are not likely to have a permanent effect on the future productivity of the heifer they will decrease her growth rate and hence delay sexual maturity. This increases rearing expense and hence decreases profitability.

The feeding of a high-quality roughage such as leguminous browse or the rotation of heifers over good grasslegume pastures such as guineacentro, should ensure that they grow at a reasonable rate; but in the wet and dry tropics or in the semi-arid tropics it may be necessary to supplement their diet during the dry season. Supplements could be good legume or grass hay, silage, molassesureamineral liquid feeds or blocks or cheap protein-rich concentrates such as groundnut or cottonseed meal. Yearling heifers fed 0.25 kg per head per day of such concentrates, and maintained on only medium-quality roughage, will materially improve their liveweight gain and shorten the time taken to attain sexual maturity.

Like calves, heifers can be reared indoors or outdoors. As indoor rearing is so expensive heifers are not usually housed in the wet tropics, although in many regions they may be kept indoors until they are 912 months of age. However, in some wet tropical regions it is essential to rear heifers indoorsparticularly in those regions of Africa where the tsetse fly is prevalent, unless cattle tolerant of trypanosomosis such as the N'Dama are being utilized. The latter is unlikely as the indigenous breeds of cattle that are tolerant of trypanosomosis are poor milkers. Also there are countries such as Mauritius, where biting flies are so numerous that heifers must be housed in screened or dark sheds. There are also regions in Central and South America where cattle are liable to be bitten by vampire bats, the vectors of rabies, and so must be housed at night.

There is no doubt that in the tropics, temperate- and tropical-type cattle do not generally grow as quickly as do temperate-type cattle in the temperate zone, although they may eventually achieve the same mature liveweight. In New Zealand it has been shown that under outdoor conditions growth depends very largely on grazing management. Although the effect of the climatic environment is of some importance in the wet tropics (Hancock & Payne, 1955), grazing management practice is still a major factor in the growth of heifers. They can either be set-stocked or rotationally grazed, rotational grazing being rarely practised. Experimental work in New Zealand has shown that in that country rotationally grazed heifers can weigh 68 kg more than set-stocked heifers at 20 months of age, and unlike set-stocked heifers do not have to be drenched at regular intervals for the control of internal parasites. One reason why set-stocked heifers do not thrive as well as rotationally grazed heifers is that they have to work harder to obtain their feed. In the New Zealand experiments, rotationally grazed heifers grazed for 7.5 hours each day, taking 48 bites per minute, whereas set-stocked heifers required 9.0 hours of grazing and took 35 bites per minute. The significance of these findings is likely to be even greater in the tropics than in New Zealand, as any increase in muscular work in the tropics increases the heat load on the animal with a consequent depressing effect on liveweight gain.

There is no doubt that a major part of the poor growth of heifers in the tropics is due to their poor nutrition, often the result of set-stocking on low-quality pastures or the complete absence of pastures, although in the case of indigenous cattle some part of the poor growth may also be due to inherited characteristics. Another part of the slow growth of both exotic and indigenous heifers (perhaps 10%) is due to the effect of the climatic environment (Hancock & Payne, 1955).

Heifers raised outdoors should be managed as follows. They should always be rotationally grazed around paddocks containing grass of milk-producing quality, or if the quality of the forage is poor they should in addition be fed a supplement. If the milking herd grazings are utilized then the heifers should be rotated 710 days ahead of the milking cows. A minimum of 14 paddocks is required in order to exploit rotational grazing techniques; preferably, more paddocks should be available. The heifers should be shifted daily if this is practicable and never grazed on any one field for more than 2 or 3 days. The paddocks should be provided with natural and/or artificial shade and water. A mineral mixture should be available in rainproof feeders and similar provisions should be made for the feeding of any supplement that may be required.

Heifers raised in yards should have access to cool water, shade, minerals, forage and if necessary a supplement. The shade should be orientated eastwest, be approximately 3 m in height and be constructed from suitable materials. Some form of thatch roof on timber uprights may be very suitable, but it could harbour vermin. If corrugated iron is used as a roofing material then it should be painted black underneath and with aluminium paint on the upper surface. Aluminium and asbestos are excellent roofing materials, but they may be too expensive and the use of asbestos is forbidden in some countries.

Heifers raised in yards can be fed cheap roughages and/or crop by-products such as straw, stover, pineapple pulp, sisal waste, etc., but they will also require additional high-quality forage and concentrate supplements. Feeding standards for growing heifers are provided in Table 7.13.

As stated previously, the heifers of many tropical and temperate breeds managed in the tropics grow so slowly that sexual and conformation maturity occur at approximately the same age. In the temperate zone, heifers from the smaller dairy breeds are usually first bred at approximately 15 months of age while those of the larger breeds are first bred at about 18 months, although there has been a general tendency to breed them earlier since the 1960s, as weight for age has improved. The majority of heifers in the tropics are too small, and hence too sexually immature, to breed at these ages and normally first service does not take place until they are older (Table 7.14). It is recommended that liveweight rather than age should be used as a criterion as to when heifers should be first bred. Adequate liveweights would be 200225 kg for the smaller and 290315 kg for the larger breeds.

After the heifer has been bred and conception has taken place she not only has to continue to grow but also to produce a viable calf and to milk 9 months later. She therefore requires somewhat better feeding than some other classes of dairy cattle, particularly during the last 2 months of pregnancy. It is advisable to bring her into the milking herd at this time. She can than be fed a little extra concentrate feed in the milking bail and in addition she becomes accustomed to being handled. If the heifer is of a high-producing breed then an additional 1.8 kg of a milk production concentrate ration may be fed. This additional feeding during the pre-pregnancy period is known as 'steaming-up'.

Internal parasite control should be continued throughout the heifer's growth period in the wet tropics and, if required, in other ecological zones. All heifers should be vaccinated with Strain 19

Table 7.13 Daily nutrient allowances for growing cattle. (*Source*: Adapted from McDonald *et al*., 1981.)

Liveweight (kg)	Dry matter intake[a] (kg)	At a liveweight gain of 0.6 kg/day					
		EMP[b] (MJ)	DCP (g)	Ca (g)	P (g)	Na (g)	Vitamin A (IU)
200	45	26.5	380	22	11	4.1	13 500
250	56	30.4	410	24	13	5.0	16 700
300	67	34.3	435	26	16	5.9	20 000
350	78	38.3	450	28	20	6.7	23 500

DCP = digestible crude protein.
a The dry matter (DM) intake is likely to be somewhat less in the tropics than in the temperate zone.
b Net energy allowance for maintenance and production.

Table 7.14 Average age at first calving of heifers of some representative tropical breeds and crosses between tropical and temperate-type breeds.

Breed	Country	Age at first calving (months) Mean	Range	Reference
N'Dama	Sierra Leone	39.4	33.248.0	Touchberry, 1967
Kenana	Sudan	38.4	23.058.0	Alim, 1960
Kankrej	Brazil	46.9		Pires *et al*., 1967
Jamaica Hope	Jamaica			
	Experimental herd	34.2		Wellington *et al*., 1970
	Private herds	35.9		
Hariana	India	39.3		Misra & Kushwaha, 1970
Ongole	India	39.9		Rao *et al*., 1969
Red Sindhi	India	51.0		Kumar, 1969
Red Sindhi × Jersey	India	31.7		Kumar, 1969
Sinhala	Sri Lanka	44.8		Wijeratne, 1970
Sinhala × Friesian (F1)	Sri Lanka	36.9		Wijeratne, 1970
Sinhala × Jersey (F1)	Sri Lanka	36.6		Wijeratne, 1970

against contagious abortions when they are between 4 and 8 months of age. Where foot and mouth disease is endemic they should be vaccinated twice or three times a year against the indigenous strains of the disease, and in endemic rinderpest areas they should be vaccinated against this disease when they are approximately 8 months of age. In those regions where the diseases are endemic, heifers should also be vaccinated against blackleg and anthrax.

The Milking Heifer and Cow

Management and Feeding during Breeding

Data from tropical breeds are limited, but it is likely that the normal variation in the gestation period of cows in the tropics is between 275 and 287 days, as in the temperate zone. The normal variation in the period between heats of 1824 days is also similar to that in the temperate zone. There is, however, a major difference in the duration of heat. In the temperate zone the duration of heat averages about 18 hours with a range of from 6 to 30 hours. In the case of temperate type breeds in the tropics and many indigenous tropical breeds, including the majority of zebu breeds, the average duration of heat is far shorter. In addition the short heat period often occurs at night and 'silent' heats are common. There are exceptions to this generalization as many of the indigenous breeds in Southeast Asia, and particularly the Madura and the Bali, exhibit longer than average heat periods. However, these breeds are not likely to be used for milk-production purposes as they are very poor milk producers, though crossbreds of them with temperate-type breeds might be used.

The short duration of heat and the fact that the heat period so often occurs at night complicates breeding management in the tropics. As a consequence, fertility is often very low in both temperate- and tropical-type dairy cattle unless special managerial measures are employed. This is particularly so in Holstein and high-grade Holstein dairy herds. The use of artificial insemination (AI) is not recommended unless special arrangements are made for heat detection in the heifers and cows and the general standards of management are high. Even if AI is utilized 'back-up' dairy bulls should be available to breed heifers and cows that are missed during the operation of the normal AI programme. Heat detection may be improved by the use of vasectomized bulls equipped with a head stall, managed with the heifers and cows. The bulls will mark female stock coming on heat. Other heat-detection equipment may also be used such as phials of dye attached to the back of the female that burst when she is mounted, either by another female or by a vasectomized bull.

Dairy cows usually come into heat some 3060 days after calving. In the tropics the most suitable practice would appear to be to breed the cow at her first heat period after calving and not later than 60 days after parturition. If she is not bred at this time the available evidence suggests that she will be more difficult to get in calf. There is also some evidence that the chances of a successful first service are less in the tropics. A percentage of heifers and cows are, of course, always sterile in all herds, and in the temperate zone the incidence of sterility in females up to 10 years of age varies from 3 to 5%, although when they are older than 10 years the percentage rises rapidly. There is no evidence that the percentage of completely sterile animals is markedly different in the tropics.

Culling for sterility is essential, and persistent culling in a closed herd should gradually improve the fertility of the female stock. It is also possible that culling for short heat periods and 'silent' heats may also be effective in reducing the incidence of these characteristics, although the author does not know of any experimental work that has been conducted on this subject. It is likely that some considerable part of this phenomenon is due to the effect of the climatic environment so that culling could only be partially effective. In addition the heavy culling of heifers and/or cows for reproductive behavioural defects in tropical dairy herds is often difficult if not impossible on account of high calf mortality, with the consequence that there are only a limited number of heifer calves available annually for replacement purposes.

It is normal to run a bull with the grazing heifers, some arrangement being made for the daily identification of those that he has served. It is, therefore, important that individuals within groups of heifers should be of approximately the same size and weight. Running a bull with the milking herd is not a very desirable practice. It is more satisfactory to keep the bull adjacent to the milking shed and to take cows that are on heat to him. In order to do this satisfactorily some method of heat detection, as described above, must be employed.

If a cow does not have a dry period between lactations subsequent yield is likely to be reduced. Cows that calve regularly, at approximately 12-month intervals, should be milked for 10 months or for a 305-day period and rested for 2 months. The dry period allows the cow's mammary glands to rest and recuperate and enables her to complete the building up of a body reserve of nutrients ready for the next lactation. For example, one study has shown that a dry period of 55 days resulted in an overall loss of 4.6% of the total milk produced in the current lactation, but a gain of 28.7% in the following lactation, or a net gain of 24.1% in total milk production in the two lactations. Heifers should be allowed longer dry periods than cows, particularly in the tropics where they are likely to continue to grow throughout the first lactation. They should be dried off after approximately 260270 days and given a 90- to 100-day dry period. Undersized heifers should be given a particularly long first dry period, as should cows in a poor condition. In practice, as short lactations are characteristic of both temperate- and tropical-type cattle managed in the tropics the problem that usually confronts the farmer is that the dry period is too long. For example, Mahadevan (1955) stated that 25% of the lactations of unimproved zebu cattle end before 300 days, so that the lactation yield of these cattle is closely correlated with the length of the lactation. In a later publication (Mahadevan, 1966) it was stated that this correlation also existed in temperate-type dairy cattle managed in the tropics. It is likely that the relatively short lactation periods demonstrated by tropical dairy cattle are primarily the result of environmental factors and that as standards of management and feeding improve the situation may change.

At the present stage of development of the dairy industry in the tropics, as the average lactation length is so short, it might be economic to pursue a managerial policy that would increase the total number of milking cows on the holding and systematically dry-off the milkers after a lactation of 240 days, thus increasing both the stocking rate and the proportion of dry cows in the herd. The dry cows could, however, be fed on a low maintenance ration, and this policy would enable the farmer to shift both forage and concentrate feed resources from relatively non-productive to relatively productive animals. Essentially, this policy would mean that the farmer would milk more cows, but that each would be milked for a shorter period and that he would use available feed resources to provide maximum feed during the most productive part of the lactation.

Temperate-breed heifers raised in the temperate zone normally produce, during their first lactation, 7077% of the milk that they will produce when they are mature. Also, cows attain their maximum production at the fourth or fifth lactation, with production declining after the seventh or eighth lactation. Analysis of milk production data from the tropics has suggested that maximum production occurs at an earlier age (Mahadevan, 1966). There is, however, some evidence that this phenomenon may also be due to inadequate feeding and management and may not be an inherent characteristic of dairy cattle managed in the tropics.

A cow or a heifer about to calve should be placed in a pen or in a separate paddock so that she can be kept under observation. The advantage of a special calving box is that the animal can be kept under close observation and that if she does have difficulty during calving assistance can be immediately provided. However, unless calving boxes are kept scrupulously clean there may be more disadvantages in bringing the animal inside than in leaving her out in the field. She should not be interfered with during calving unless she is obviously in trouble. At calving the heifer or cow loses 810% of her body weight.

During the calving period the heifer or cow should not be overfed. A small quantity of a laxative concentrate such as rice bran is a useful feed at this time. After calving, concentrate feeding, if not already begun during the previous 2 months, should be commenced immediately and should reach a peak within approximately 3 weeks. The cow or heifer should always be fed a little more concentrate than her milk yield justifies in order to encourage milk production to rise during the first stage of the lactation.

Management

The aim of good management of dairy cattle in the tropics should be to take all economically justifiable measures that will decrease the total 'heat load' of the animal or help to spread the 'heat load' more evenly over the 24 hours. As temperate-zone methods of management are not based on this premise they are not necessarily suited to the tropics. Within the limits of present knowledge suitable managerial practices would appear to be:

(1) The provision of rations that do not exceed optimal requirement with particular reference to total energy and fibre content. Grazing at night but not during the daytime. Concentrate feeding in the early morning and early evening or the spreading of concentrate feeding throughout the 24 hours instead of only feeding during the day.

(2) The provision of adequate and cool water supplies both in yards and out on grazings.

(3) The siting of yards, milking bails and shelters so that they are open to the prevailing winds but not to driving rain. The provision of adequate natural or constructed shade in yards and out on the grazings and the choice of suitable materials for shelter construction.

(4) The clipping of the coats of animals that are managed indoors and are sheltered from solar radiation. This is not normally necessary in the case of tropical breeds.

(5) The seasonal breeding of heifers and cows to calve down during the coolest season if seasonal milk production is economic.

(6) The provision of water sprays, forced air fans and cooled water supplies in the yards, bails and shelters if the use of these practices can be economically justified. This depends primarily on the cost of energy.

Milking cows, like calves and heifers, can be managed indoors or outdoors or on an indoor

outdoor system. It is now generally agreed that in the wet tropics temperate or crossbred-type animals are more productive than tropical-type cattle if disease control is adequate and they are properly fed and managed. A tropical climate, however, always imposes some degree of stress on milking cattle, and although there will be wide individual variations in yield there is probably a physiological limit to average milk production, the 'ceiling' being lower than it would be for cattle of the same inherent merit managed in a temperate climate (Payne & Hancock, 1957). On the other hand, with good husbandry, total forage production per unit area of land can be maintained at a very high level and it would be logical for the dairy farmer in the wet tropics to aim at a high stocking rate and a high production per unit area rather than a high production per animal. Of course, a high production per unit area cannot be attained without relatively high production per animal. In addition, the ability of the dairy farmer to grow forage in the wet tropics is probably well ahead of his ability to utilize it efficiently. All these factors must be considered in any assessment of the most suitable type of managerial system.

The advantages and disadvantages of an indoor system in the wet tropics are as follows:

• *Advantages*:

(1) It is easier to take managerial measures that will decrease the total 'heat load' if cattle are managed indoors, at least during the day.

(2) Maintenance requirements should be slightly lower and muscular heat production reduced if the cattle are not grazing or walking backwards and forwards twice a day to the milking shed.

(3) Higher carrying capacities can be achieved, according to some authorities, if forage is cut and not grazed. Cut forage will certainly be wilted before it is fed and this may help to maintain a higher dry matter intake.

(4) Grazings will not be spoilt during wet weather.

(5) Manure can be returned to the fields more evenly and by-products such as straw and sawdust can be converted into organic manures in the yards.

(6) Maximum utilization can be achieved of high-growing forage species such as elephant grass (*Pennisetum purpureum*), that are more difficult to manage under grazing conditions and that yield large quantities of dry matter per unit area.

(7) Under circumstances where large quantities of by-products are available for feeding, as when dairying is integrated with citrus, pineapple or sugar production.

• *Disadvantages*:

(1) Capital requirements are far higher although there would be some savings in the cost of water reticulation to fields, internal fences and roads. The exception would be the very small farmer who tethered one or two dairy cattle beneath trees or who built simple yards. Examples of the latter type of indoor management may be seen on the islands of Bali and Madura, in Indonesia or in Mauritius.

(2) Labour costs are higher. If the cost of labour is low this may not be a serious disadvantage.

(3) The difficulty of maintaining high-quality forage mixtures, particularly grasslegume mixtures, without grazing. This could mean an increase in fertilizer costs or a decrease in the quality of the feed.

(4) The managerial difficulties of organizing a constant flow of high-quality feed to yard-fed cattle, particularly during very wet periods. This difficulty should not be underestimated.

(5) A general lack of flexibility.

The decision whether to adopt an indoor or an outdoor system of management depends primarily upon the ecological conditions. The economics are simple. Will the increased production resulting from an indoor managerial system that ameliorates conditions for the cattle pay for the

additional cost of the buildings and equipment required and the cost of bringing feed to the animals and disposing of the waste products? In the wet tropics, although there are some regions where cattle have to be housed on account of parasites, etc., it is likely that in most regions some form of indooroutdoor system would be most suitable and efficient although it is not known whether it would be the most economic. This could only be determined locally. With an indooroutdoor system milking cattle could be kept in the yards during the day, when ameliorative measures against the climatic environment could be taken, and grazed on the pasture at night. Surplus forage would be ensiled and fed to the cattle when they were yarded during the day. Some conserved fodder would be fed throughout the yearsmall quantities when the night grazings were adequate and larger quantities during the very wet or very dry periods when the cattle would be kept off the grazings even during the night. Under this type of management the cattle would not be continuously changing from one type of feed to another but would always receive some conserved fodder whether or not they also grazed. The system would be inherently very flexible.

In the semi-arid tropics it is likely that an indoor system would be a necessity, though this will depend upon whether irrigation is available. In the ecological zones between these two extremes the decision will vary according to local circumstances. Unfortunately at the present time there is no objective information on this fundamental question in any ecological zone.

Whether managed indoors or outdoors milking cows exhibit very definite behavioural patterns. They demonstrate a well-established herd order and are very quick to associate pleasant or unpleasant experiences with places and/or persons. They should always be handled quietly and according to a strict routine and if possible by the same person(s).

Cows managed indoors often develop long hooves. These should be trimmed periodically. Cows managed outdoors, particularly in the muddy conditions that occur in the wet tropics, often develop soft pads that are invaded by infectious organisms that cause lameness. It is good practice to walk these cattle through a foot-bath containing a copper sulphate or formalin solution, either at regular intervals or daily as a routine measure, perhaps as they leave the milking bail. Some dairy stock managed indoors develop the habit of suckling each other and odd individuals will suckle themselves. This habit can be prevented by attaching a short length of chain to one or two rings in the nose.

The habit of kicking is usually developed when a heifer is first milked and is due to faulty management. Once acquired it is a difficult habit to break and as kickers disturb the milking shed routine they should be culled. Some cows can become vicious. This is usually due to poor management. In the early stages the habit may be broken by a few sharp blows on the nose. If this does not effect a cure the cow should be culled.

There is no evidence that grooming improves the health of dairy cattle although it does accustom them to handling. It is a desirable practice if the farmer has spare time. However, it is a very rare individual who has sufficient time to spare for this practice.

Feeding

If dairy cattle are managed outdoors the method of management of the grazings is of major importance.

Grazing Management.

Grazings can of course be managed in a variety of different ways. At one extreme they can be set-stocked by using the whole area at the same time, and at the other extreme cattle can be rotationally grazed around very small paddocks or 'folded' across the grazings. The method adopted depends on a variety of circumstances, but the high stocking rates required in the wet tropics make it almost obligatory to use some form of rotational grazing. It has been observed in the Philippines that crossbred dairy cattle, managed under an extremely rapid type of rotational grazing system, grazed for longer periods during the day when the grass was young and succulent. It can be theorized that under these managerial conditions the 'heat-load' due to digestive heat production was minimal so that the cattle could withstand a slightly higher 'heat-load' due to radiation. It has

also been noted that when dairy cattle were grazed in a field where the grass growth was sufficient for more than two successive grazing periods, the cows grazed the best grass first, progressively spent fewer daylight hours grazing and spoilt a great deal of grass by trampling on it when it was long.

It would appear that the most logical method of managing dairy cattle in order to ensure maximum utilization of the fodder available would be to graze them rotationally over as many small paddocks as is practical. The cattle should be grazed in any one field for as short a time as possible, so that they are always able to obtain new and succulent forage. The shortest practical time is that between milkings, i.e. usually 1012 hours, and maximum utilization is obtained by stocking paddocks as heavily as possible for this period. As tropical forage plants grow and mature more rapidly than temperate forage plants under optimal conditions, it is necessary to return the cattle to the same field more rapidly than would be the case in the temperate zone. It is likely that maximum utilization is obtained by rotating cattle around the paddocks once every 1015 days. There are, however, only a limited number of forage species that can withstand this intensity of rotation, and in practice the rotation will probably have to be longer. In order to make certain that every cow receives her fill, slightly more grass needs to be offered than the whole herd is able to consume. This means in practice that some grass is left uneaten after each grazing and that there is a gradual build-up in the proportion of mature grass in the pasture. This can be corrected by utilizing the dry cows to 'eat out' the field every few months and then cutting whatever mature forage remains. After this treatment there should be immediate regrowth, but it is considered desirable to 'spell' the pasture at this stage in order not to reduce unduly the grazing plant's food reserves.

The heavier the stocking rate the more necessary it becomes to correctly apportion available forage between the various groups of cattle. Calves should, as suggested previously, be rotated ahead of the milking herd. Heifers and young bulls should receive the next priority; dry cows, not calving within 2 months, the least priority.

The best grazings should always be reserved for grazing at night, as experimental work has shown that the higher producing cows graze for a longer period at night than during the day.

Grazing is not generally recommended as a managerial method for dairy cows in the dry tropics.

Forage Conservation

There are several methods of adapting the seasonal supply of fodder to the demands of the dairy herd. The one that is probably most often used is to conserve surplus fodder and utilize it in times of scarcity. It is also possible to reduce the fluctuations in forage production by applying fertilizers at the appropriate time, by irrigation in the dry months or by purchase of extra feeds from outside the farm during periods of feed scarcity. Under certain circumstances it is possible to adopt seasonal calving so that cows' maximum demands for feed are equated with maximum seasonal forage productivity. Seasonal calving is certainly suitable for beef operations and for the production of milk for manufacturing purposes, but is not suited for a whole milk supply operation, in which consumption demand does not fluctuate from season to season.

In the dry tropics there is usually a very long dry season, and under some circumstances it may be economic to store surplus feed produced during the wet season either as hay or as silage. There is usually no difficulty in making hay in the dry tropics, and in regions where there is no rain during the dry season the forage can be left standing in the field. Under these circumstances the conserved product is known as 'standing hay'. Pit silage or other forms of silage can usually be made, although much silage that is made in the dry tropics is of rather poor quality. This is probably due to the fact that fodder crops are usually allowed to become over-mature before they are cut and filled into the silo. Over-mature forage of this type is not only unpalatable and of low nutritional value but it is difficult to exclude air from it when being packed in the silo, with a consequent increase in silo losses. In the wet tropics, in particular in the equatorial region, there may be no long dry season. What is more usual are relatively short spells of dry weather. These and perhaps periods of intense rainfall cause fluctuations in the supply of forage, and what is required are relatively small quantities of conserved fodder to feed for short periods. Hay-making is very difficult in the wet tropics, but silage can easily be made, and as long as the forage is not too mature and the weather is not too wet, good silage can be made. One problem is that continuous silage-making may be difficult, so that if silage is made in large bunkers it may be necessary to intermittently close and open them with consequent loss of nutrients. What is probably required on the average farm are a number of relatively small silos that can be filled with the forage cut from a small number of paddocks. Pit silos are not usually practical in wet tropical environments and some form of above-ground silo is usually required.

Feeding Standards

Once a cow has commenced milking she becomes a mainstay of the farm income and should be treated accordingly. Good milking cows cannot consume as much feed as they are capable of converting into milk following calving and normally they utilize their body reserves at this time. During this period the cow is not only producing the most milk but it is likely that she is producing it more efficiently than at any other time, so she should be offered as much feed as she will eat. Once the cow has passed the peak of lactation and, as stated previously, this may be often a shorter period after calving in the tropics than it would be in the temperate zone, she becomes a less efficient converter of feed into milk and overfeeding will not result in any appreciable increase in production and may mean a waste of feed resources. At this stage the rationing of feed according to production will be most economic.

As tropical forage varies so widely in quality it is difficult to establish basic feeding standards for dairy cattle. In the wet tropics high-producing cows may have some difficulty in obtaining a sufficient quantity of total dry matter because of the low dry-matter content of the forage, and it is generally accepted that for the major part of the year they are more likely to have difficulty in obtaining a sufficient supply of energy than of crude protein (Hardison, 196768). It may be assumed, however, that well-managed pastures in the wet tropics will provide for the maintenance requirements of milking cows and for the production of approximately 4.5 litres of milk. Cows that are producing more than 4.5 litres of milk a day should be fed concentrates at a rate based on the data given in Table 7.15. In the semi-arid tropics it is likely that pastures will provide only maintenance requirements for part of the year and for maintenance and some part of the milk production during the wet season, unless irrigation is available. At all other times the maintenance requirements will have to be provided by cut fodder, hay or silage fed in the yards or on the pasture, possibly supplemented with molassesureaminerals liquid feed or some similar food.

The variety of concentrates available for the feeding of dairy cattle in the tropics is considerable, but in a general treatise it is impossible to recommend different mixed rations produced from the feeds available in all regions.

If it is practical, each cow should be fed its concentrate ration separately, the amount varying according to its production. This may not be an economic practice everywhere, and one alternative is to divide the milking cows into a limited number of groups based on their approximate milk production and date of calving and to feed each group a standard ration. It is normal to feed concentrates at the bail at milking times. For large dairy herds semi-automatic or automatic feeding devices can be installed, but some of the same reservations apply to the installation of this type of equipment in tropical countries as apply to the installation of milking machines; the difficulty of efficient maintenance.

Cows should have access to ample supplies of water in both paddocks and yards. It should be noted that the water consumption of dairy cows in the tropics is at least twice that of dairy cows in the temperate zone (Payne & Hancock, 1957) so that the necessary arrangements must be made to see that the cows obtain a sufficient supply.

A complete mineral mix should be added to

Table 7.15 Feeding standards for dairy cattle. (*Source*: McDonald *et al*., 1981.)

I Maintenance (daily allowance)

Liveweight (kg)	ME (MJ)	DCP (g)	Ca (g)	P (g)	Na (g)	Vitamin A (IU)
350	40	220	13	14	6	30 500
400	45	245	14	19	7	34 500
450	49	275	16	22	8	39 000
500	54	300	18	26	9	45 000
550	58	325	20	29	10	48 000
600	63	345	21	33	10	52 000

II Lactation (allowance/kg milk)

Fat content (%)	SNF content (%)	ME (MJ)	DCP (g)	Ca (g)	P (g)	Na (g)	Vitamin A
3.5	8.6	4.9	51	2.7	1.7	0.63	As for maintenance
4.5	9.0	5.7	63	3.0	1.7	0.63	As for maintenance

ME = metabolizable energy; DCP = digestible crude protein; SNF = solids-not-fat.

the concentrate ration or be made available to the cows in separate feeders.

Milking Technique

The object of milking is to obtain the maximum quantity of milk from the udder. If milking is incomplete there is a tendency for the cow to dry off too soon and total milk production declines. If too long a period is spent on milking the cost per unit weight of milk produced increases. The first essential in milking technique, particularly when milking a heifer for the first time, is to prevent the animal becoming excited or frightened. The second essential is to milk quickly and completely. These objectives apply whether the animal is hand or machine milked.

The let-down of milk is controlled by a combination of nervous and hormonal actions (Fig. 7.49). The cow first needs stimulus. When the calf suckles, the first pull of the calf on the teat is the stimulus. When there is no calf some other stimulus must be established. It could be the application of a towel during preliminary udder washing or the pressure of the teat cups of a milking machine, etc. Once a stimulus is established the nervous system relays a message to the posterior pituitary gland which then releases a hormone known as oxytocin. This hormone circulates in the blood, is carried to the udder tissue, and there initiates the let-down process. As the hormone is in circulation for only a short period (up to 4 minutes), the more quickly milking is carried out the more efficient it will be. With both hand and machine milking the establishment of a strong stimulus associated with the preliminaries of milking, that will initiate the letdown reflex, is essential for fast milking. The aim is to produce a single let-down response at such a level that, with normal milking, all the milk can be obtained without the need to induce a second let-down.

The maximum rate of milk flow during the let-down process is a highly inherited characteristic that differs from cow to cow. Of major importance in this respect is the size of the orifice of the teat. Cows possessing teats with small orifices are known as hard milkers. It is desirable to cull these animals.

The actual process of milking is accomplished by the application of force to the muscles surrounding the teat meatus so that the orifice of the teat is opened and the milk discharged. In hand milking, the upper part of the teat is closed tightly by the hand to prevent milk flowing back

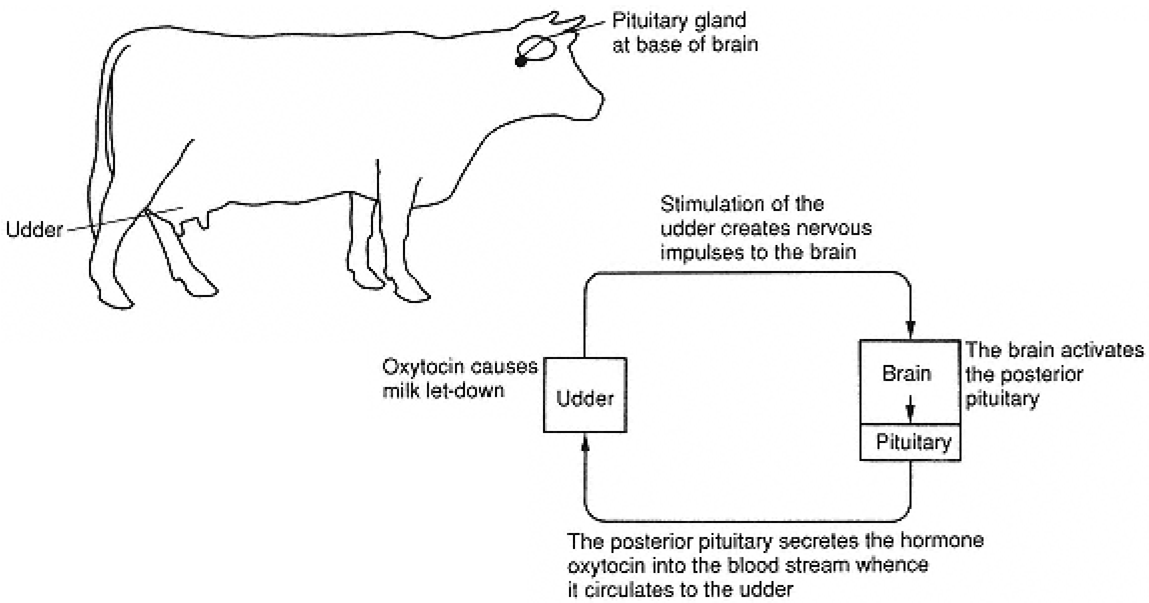


Fig. 7.49
A diagrammatic representation of the milk let-down system.

into the udder cistern while pressure is applied to the milk-filled lower portion of the teat (Fig. 7.50(a)). Increased pressure inside the teat stretches the sphincter muscle and the teat meatus is forced open. In machine milking the pressure on the inside of the teat is unchanged. The pressure inside the teat cup is lowered so that a vacuum is formed (Fig. 7.50(b)) and the normal pressure inside the teat in relation to the pressure outside becomes sufficient to force the teat meatus open and allow the milk to flow out. If milk does not flow the vacuum extends inside the teat causing damage to the mammary tissues. This is why the teat cups must be taken off as soon as milk flow ceases.

In hand milking it is better to milk with dry rather than wet hands as wet hand milking is unsanitary. Hand stripping should be completed as quickly as possible, otherwise the cow may become a 'stripper' and only let down her milk very slowly. Cows milked by machine should be machine and not hand stripped.

Cows are usually milked twice daily at approximately 12-hour intervals. However, experimental work in Australia and New Zealand has shown that there is no significant change in the average hourly excretion of milk by cows from 12- and 12-hour to 16- and 8-hour milking intervals. The dairy farmer can therefore exercise some considerable choice in milking interval without endangering the overall productivity of his cows. It is usual to restrict milking gradually in order to dry off a cow. The pressure that develops in the udder soon stops milk production. As stated previously all cows should be dried off at 305 days, even if their milk production is still high, if they are going to calve 12 months after the beginning of their current lactation. Cows should be dried off before 305 days only if they are due to calve or if they produce so little milk that it becomes uneconomic to milk them.

Sometimes a cow's teat leaks milk before milking. This may be due to two causes. The muscles of the orifice may be weak, or there may be a natural fistula or wound in the teat cistern. A wound may be sealed by cauterization or by surgical treatment when the cow is dry. If teats are sore they should be bathed in a warm salt solution and vaseline applied.

High-producing cows may with advantage be milked more frequently than twice daily, and three times a day milking may increase total milk

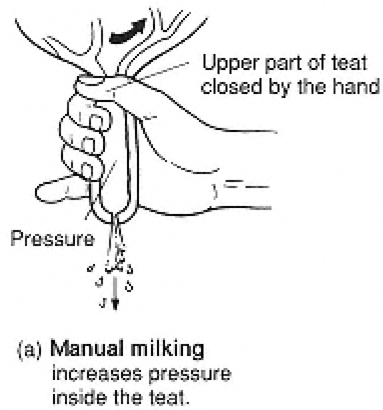
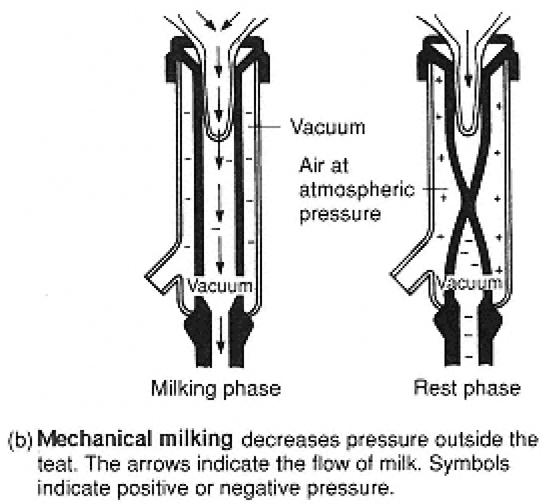


Fig. 7.50
The differences between (a) manual



(b) mechanical milking.

production by approximately 10%. The increased production obtained by milking three times a day is not due to the cows exhibiting high per hour excretion rates, but to other factors.

Hand Versus Machine Milking

It is generally accepted that machine milking is not quite as efficient a method as is the best hand milking, but that it is generally superior to average hand milking. Cows accept machine milking just as well or even better than hand milking.

Machine milking is likely to be introduced if labour is scarce and expensive, if available labour dislikes the toil of hand milking and if a sufficient number of cows are milked to justify the installation of a machine. None of these criteria apply on small dairy farms in most tropical countries. There is usually a surplus of labour, labour is often cheap and the average size of the herd is small. Even if a farmer manages a large herd and there is no surplus of labour there are other disadvantages in the installation of milking machinery. Machines are more expensive to purchase than they would be in temperate countries, spares are often difficult to obtain and there is usually a lack of skilled mechanics. As a consequence of this situation only a small proportion of milking cows managed in the tropics are machine milked. However, it can be assumed that the total will slowly increase.

Disease

Mastitis is the most common disease in milking cows in both temperate and tropical regions. It is closely associated with the method of management adopted and may be caused by a number of different types of pathogenic bacteria. Mastitis control must be viewed as a continuing process. The disease can be effectively controlled if there is a strict and proper use of the strip cup, so that infection is detected at an early stage, proper washing of the udder and teats, proper hygiene and sanitation in the dairy yards and buildings, good machine stripping, the milking of infected cows either separately or at the end of the milking process, the proper treatment of infected teats and/or udders and the segregation or culling of cows suffering from chronic and incurable mastitis.

The vaccination programme recommended for heifers in a previous section should be continued during the life of the milking cow where the vaccinations have to be repeated at definite intervals in order for immunity to be maintained.

The Dry Cow

Dry cows not due to calve within 2 months can be considered as non-productive, and every effort should be made to see that their number is kept to a minimumunless a managerial system is adopted where milking cattle are dried off early. They must, however, be properly managed during their dry period in order to ensure high productivity in subsequent lactations. Climatic stress will, however, be at a minimum during this period.

As lactating cows utilize energy more efficiently for liveweight gain than do dry cows it is probably more profitable to allow cows to regain the body weight lost in the early stages of lactation during the latter stages of lactation rather than during their dry period. The aim during the dry period should be to maintain the cows in good condition but not to allow them to fatten. Under grazing conditions dry cows can be used to 'clean up' pastures after the milking herd or to graze the poorer pastures on the farm. They should seldom require concentrate feeds, but they may need to be fed additional minerals. Dry cows managed in yards should be fed medium quality forage and have access to adequate supplies of water and minerals.

Attention has already been focused on the desirability of 'steaming up' dry cows as from 2 months before calving. Nutrient requirements during the 'steaming-up' period are given in Table 7.16.

The Bull

The selection of a suitable bull is very important as it is said a sire is 'half the herd', i.e. half the inherited characteristics of all the calves are obtained from him. Bulls may be selected by type, by pedigree or by sib or progeny performance. The relative merits of each type of selection have been discussed in Chapter 4.

Table 7.16 Additional daily nutrient allowances for dry cows during the period of 2 months prior to calving. (*Source*: Based on McDonald *et al*., 1988.)

Month of pregnancy	ME* (MJ)	DCP* (g)	Ca* (g)	P* (g)	Na* (g)
8	12	135	11	7	2
9	29	244	11	7	2

ME = metabolizable energy; DCP = digestible crude protein.
* These allowances are in addition to the maintenance allowance for a cow of a specific liveweight.

The chances are that the average dairy farmer in the tropics has little opportunity to select a suitable bull; he simply accepts what bull is available, irrespective of merit. This situation, however, does not exist in large-scale projects where temperate-type dairy bulls or the semen of temperate-type dairy bulls are used for upgrading purposes. A choice is usually possible. The project organization can adopt one of the following alternatives:

(1) Import progeny-tested bulls or semen from progeny-tested bulls. These alternatives are both expensive. As imported, exotic progeny-tested bulls are scarce and expensive and will probably have a high mortality in a tropical environment, it is preferable to import semen and operate an artificial insemination service. The organization can then breed either pure or crossbred bulls for distribution to individual farmers. On account of the likely high mortality of purebred bulls, it is preferable to distribute crossbred bulls.

(2) Import a large number of non-progeny-tested bulls from highly productive herds. If a high wastage rate is acceptable some of the imported bulls will acclimatize. Bulls should be purchased from herds in subtropical or warmer temperate-zone regions such as Florida and Louisiana in the United States, the highlands of Kenya or Israel in order to improve the chances of acclimatization.

(3) Attempt to heat-tolerance test suitable bulls from highly productive herds before importation. This procedure will at least ensure that the bulls have a better chance of surviving in the tropical environment into which they are imported. This method was attempted in Fiji in the 1950s with favourable results. Six bulls that were considered to be of approximately equal merit as regards the inheritance of production characteristics were selected and heat-tolerance tested in their country of origin. The bull that demonstrated the highest heat tolerance was imported into Fiji. As far as the authors know no further efforts have been made to develop an importation scheme using these

methods. It is also now possible to obtain bulls or semen from purebred and crossbred tropical-based dairy herds. Examples are the Australian Milking Zebu stock in Australia and the Jamaica Hope breed in Jamaica.

Management and Feeding

The general management and feeding of young bulls should be similar to that of heifers. Every effort should be made to feed them adequately so that they can be brought into service at as early an age as possible. When fully grown they should be kept in a vigorous physical condition and should not be allowed to get too fat. On small holdings it may be necessary for economic reasons to work the breeding bull. This is practical so long as the bull is not overworked.

When mature the bull should receive the same type of roughage rations as the dry cows, together with an extra 0.91.8 kg of concentrates. He must also have access to adequate clean water and a complete mineral ration.

Bulls managed in the tropics appear to be quieter and less bad tempered than temperate-type bulls of the same breed managed in the same way in the temperate zone. However, this does not mean that precautions are not needed in the handling of bulls in the tropics. Bull paddocks should always be securely fenced. A copper ring should be inserted in the nose of the bulls by punching a hole in the septum with a special pair of pliers or some other sharp instrument. Peasant producers in most tropical countries punch a hole in the septum of the nose of their bulls and pass a rope through it with a knot at one end that is sufficiently large to prevent the rope slipping through the hole. Dehorning is desirable and will quieten almost any bull, but it may be impracticable when the bull is going to be used for work.

Daily exercise is most important for bulls. If they are managed indoors without access to a paddock they should be led at a good walking pace for some distance, either in the early morning or in the cool of the evening.

Service Management.

The active breeding life of bulls varies from approximately 5 to 16 years. The age of the bull has no influence on the quality of his offspring. In the temperate zone young bulls can be first used as early as 1012 months of age, but in the tropics bulls are not sufficiently well grown or sexually mature until they are somewhat older. In well-managed herds they might be of use at 18 months of age, but most indigenous bulls are not usually ready for service until they are 2 or more years of age and often do not attain maximum breeding powers until they are considerably older. It is possible, though not proven, that the breeding power of bulls in the tropics does not decline at as early an age as does that of bulls in the temperate zone.

Young bulls can be used once or perhaps twice a week, but older bulls maybe used up to five times a week. Mature bulls can serve up to 100 cows a year, but usually a bull is allowed to serve only 50 or 60 cows. The acceptable ratio of breeding females to breeding males is likely to be somewhat lower in the tropics than it is in the temperate zone on account of the effect of the climatic environment on the fertility and vigour of the bull.

There is now considerable evidence that the climatic environment *per se* affects the fertility of bulls in the tropics, in particular the fertility of bulls of exotic breeds. Given this situation every effort should be made to ameliorate conditions for breeding bulls by managerial means, using the techniques suggested in a previous section for the proper management of milking cows.

If it is necessary to serve very small heifers or cows using large bulls or vice versa, then special managerial precautions are required. Very large cows should be placed in a shallow pit for service by very young, small bulls, and small heifers and cows should be served in a service crate by very heavy, old bulls. The fertility of breeding bulls should be checked from time to time.

Intensive Beef Production

There are two major methods of intensive beef production. The first is to rear and fatten cattle for their whole life out in the field on pasture and/or other forage crops. The second is to manage them at some stage in their life under

confinement, often in specially constructed buildings. There can, of course, be many variations and combinations of these two managerial systems and it is likely that the majority of beef cattle that are fattened under confinement are bred and reared outdoors; some, however, in particular those purchased from dairy herds, may be reared indoors while young and fattened later on pasture.

Yard or any other indoor type of feeding management can obviously be classified as intensive, but it is sometimes difficult to decide at what stage beef production off grazings can be so classified. In this text intensive production off grazings is considered to be that form of management where the major part of the pasture and/or fodder on the holding has been specially planted and managed for beef production purposes. Thus the majority of specialist beef producers who are ley farming or integrating their cattle with crop production can be classified as intensive producers.

In general, information on the intensive production of beef cattle within the tropics is still very limited, but interest in new methods of production has noticeably quickened during the latter part of the twentieth century.

The economics of intensive production depend upon:

- The type and availability of cattle.
- The cost and availability of by-product feeds and/or the cost of intensifying pasture or fodder crop production.
- The cost of suitable infrastructure.
- The level of managerial expertise in feedlot or pasture and forage production.
- The price of beef and whether there is a local or an export demand for quality beef.
- The animal disease situation.

The most suitable breed and type of cattle to utilize is discussed in a later section. Availability and assurance of a constant supply of suitable cattle, is, however, also a major issue. For example, some form of feedlot growing out and fattening of cattle could be of considerable economic importance in the Sahel and other drier ecological zones in Africa and elsewhere. The removal of young animals from nomadic and transhumant cattle herds to be grown out and/or finished on crop by-product feeds or forage cultivated in specially favoured locations, could be very advantageous. The introduction of such a system would help to reduce grazing pressure during the driest season of the year and increase the overall productivity of semi-arid areas. Pilot-scale investigational work in Kenya demonstrated the technical advantages of such a system (Creek, 1972) but an attempt to commercialize such operations ended in failure. The major reasons for failure appear to have been the intermittent nature of supplies of feeder cattle from the pastoral areas and sometimes complete cessation of supplies due to the introduction of disease quarantine measures.

The feedlotting of pastoralist cattle in Kenya was conducted on a large scale, in contrast to an attempt that has been made in Niger to develop a small-scale feedlot system. Small farmers in the canton of Libore, south of Niamey, were provided with credit so that they could purchase cattle from pastoralists. The cattle were kept in the farmer's compound tied to a tree or a stake and feed and water were carried to them. The feed consisted mainly of crop by-products and cut grass (*Echinochloa* spp.) from the river bank but cotton seed could also be purchased. Experience has shown (Wardle, 1979) that this type of small-scale operation can be successful if credit and a minimum of technical back-up is provided.

Large quantities of cheap by-product feeds, such as molasses, bagasse, pineapple bran, citrus pulp, etc., may be available in some tropical regions. The use of some of these feeds has been discussed in a previous section. However, cereal grain, a mainstay of feedlot enterprise in the temperate zone, is not usually available for feeding to livestock in the tropics. It is either too expensive or there are insufficient supplies for human consumption.

Intensive production of pasture or fodder is unlikely to be economic in the drier areas if water for irrigation purposes cannot be supplied at very low cost. In fact unless special factors are

operating it is unlikely that intensification of production will be very economic in those areas where the annual rainfall is less than 1000 mm. As the length and intensity of the dry season decrease, and where the annual rainfall is as much as, or exceeds, 18002000 mm a high degree of intensification can be achieved by the use of the correct pasture or fodder species, fertilizers, etc. In areas receiving 12001500 mm of rainfall there would appear to be a place for alternate husbandry where the utilization of pasture and/or fodder crops in a rotation with cash crops (ley farming) would not only provide feed for intensively managed beef cattle but also assist in the prevention of erosion and the improvement, or at least the maintenance, of soil fertility. In the equatorial tropics, where there is some rain every month, intensification is likely to be the most economic.

It would appear from experimental results, that despite the relatively unsophisticated nature of the beef cattle industry in the tropics, it is already possible to produce liveweight yields per unit area of grassland in excess of those that can be expected under good managerial conditions in the temperate zone (Payne, 1968). Estimates of the potential yield of liveweight per hectare of grassland, based on pooled data from many sources, are shown in Table 7.17. These data suggest that it should be possible to raise liveweight production per unit area very rapidly.

The authors predict that ultimately it will be found that humid tropical pastures, when properly managed, possess more potential for cattle production than pastures elsewhere in the world.

Large-scale feedlot infrastructure can be expensive. Nevertheless on a small scale the costs of the infrastructure may by negligible. There are specific areas in the tropical world where small farmers have traditionally practised intensive feeding of cattle for meat production. Some examples are: the area around the towns of Moshi and Arusha on the lower slopes of Mount Kilimanjaro and Meru in Tanzania; northern Nigeria; Batangas Province on the island of Luzon in the Philippines; and the island of Madura in Indonesia. In Tanzania indigenous cattle are stall-fed in darkened huts with locally produced by-product feeds and fodder grasses cut from the roadside. The stall feeding of beef cattle in northern Nigeria is particularly interesting as this is a seasonal activity, not practised by the pastoralists (the Fulani) but by the agriculturalists (the Hausa). The latter, using cash realized from the sale of crops, purchase cattle in October or November from the semi-nomadic Fulani, who are at this time returning from their wet season grazings. The Hausa yard-feed the cattle for approximately 5 months on crop residues such as groundnut tops, guinea-corn chaff, bean hulls and cowpea hay, and then sell the cattle when they require money to purchase seeds for

Table 7.17 Estimates of the potential for liveweight production from grasslands in the humid tropics.

Type of forage and/or management	Potential productivity under good management (kg liveweight gain/ha/ year)	
	Minimum	Maximum
Natural grasslands		
Improved grazing management	1030	60100
Oversowing with suitable legumes	120170	250450
Cultivated grasslands		
Grass/legume mixtures	200300	400600
Grass fertilized with nitrogen fertilizer	300500	8001500

the next year's cropping programme. Costing of these operations has shown that Hausa farmers do not make very much profit, but they are able to first hoard and then realize capital to finance their next season's cropping. Batangas cattle in the Philippines are usually kept in small yards and are fed by-product feeds and cut forage. The latter, often elephant grass, may be specifically grown as a feed for the cattle. The situation in the island of Madura has already been discussed.

The present level in many tropical countries of managerial expertise in feedlot or pasture and/or fodder production is not very high; mitigating against the success of large-scale schemes. Considerable investigation work is also still required.

As, in general, intensive cattle production means more expensive beef production, emphasis must be on the production of quality beef that can be sold at the highest price. As there is usually only a small market for quality beef in most tropical countries, sales of quality meat depend partly on the existence of a meat export market. It is likely that to some extent, intensification of beef production will depend upon an increase in local demand for quality beef, or on the further development of a meat export market.

The Most Suitable Breeds to Use

The major difference between extensive and intensive beef production is that intensive production requires as complete a control of the major environmental factorsclimate, nutrition and diseaseas it is economically possible to obtain. It is therefore essential that the type of cattle utilized should be able to respond to any improvements in the environment that might be made, and in particular to improvements in the level of nutrition. Although experimental evidence from East Africa suggests that in the absence of climatic stress feed is digested and utilized equally efficiently by *Bos taurus* or *B. indicus* cattle (Rogerson *et al*., 1968), there is an increasing volume of experimental evidence from all parts of the tropical and subtropical world suggesting that in general *B. indicus* cattle are not as capable as temperate-type *B. taurus* cattle of responding to improvements in their plane of nutrition. In East Africa, Ledger (1968) has shown that at Muguga, where climatic stress is limited as it is situated at an altitude of approximately 2134 m, Hereford out-produced Boran cattle from weaning to slaughter both when out on grazings and when stall fed high nutrient content rations (Table 7.18). According to Rogerson *et al*. (1968) the superiority of the Herefords was due to their higher feed intake per unit of body weight. In Uganda, Joblin (1966) stated that the Teso variety of the Small East African Zebu managed on grazings at Serere did not respond to the provision of moderate supplements of concentrates, consisting of sorghum, cottonseed cake and cooked or raw cassava. Stobbs (1969), also working at Serere, stated that the grazings had been so improved that it was now essential to utilize cattle with a greater growth potential than the Small East African Zebu. Stobbs (1969), also showed that over a 2-year period crossbred Small East African Zebu × Hereford and Small East African Zebu × Aberdeen Angus produced 36% more liveweight per unit area of grazing

Table 7.18 Relative growth rates of *Bos taurus* and *B. indicus* cattle at Muguga, Kenya. (*Source*: Ledger, 1968.)

Type of cattle	Liveweight gain per day from weaning to slaughter	
	On grazing (kg)	Stall fed (kg)
Bos taurus (Hereford)	0.50	0.84
Bos indicus (Boran)	0.28	0.33

than did purebred Small East African Zebu managed in the same way under similar environmental conditions.

Thus available evidence suggests that the most suitable cattle to utilize under intensive grazing management will be temperate-type *Bos taurus* × *B. indicus* crossbreds. These will probably be more productive than purebred *B. indicus*, tropical-type *B. taurus* such as the N'Dama or the Criollo, and ancient *B. taurus* × *B. indicus* stabilized crossbreds such as the Sanga cattle of Africa and the indigenous cattle of Southeast Asia.

In Southeast Asia crossbreds between *Bos (Bibos) banteng* and *B. taurus* and *B. indicus* should be tested as these may be more suitable for the humid areas of Southeast Asia than any other type of purebred or crossbred cattle.

It is suggested therefore, that crossbreds should be the cattle of choice for all intensive grazing systems in the tropical regions of all continents. It will of course be necessary to experiment in each region in order to find out what proportion of temperate-type *Bos taurus* blood is most suitable. Francis (1970) suggested that with improving conditions of husbandry and disease control approximately 50% of *B. taurus* blood would appear to give the most productive animals in many tropical countries. This suggestion has received support from many authorities (Payne & Hodges, 1997).

The use of stabilized crossbred breeds such as the Santa Gertrudis should also be considered under intensive grazing conditions, particularly on small holdings.

In those tropical countries where there are extensive highland areasand the continental montane areas are surprisingly large (Table 7.19)and endemic disease is well controlled there would appear to be no reason why purebred temperate-type *Bos taurus* beef breeds should not be utilized. They could perform a dual purpose, produce beef and provide bulls to be used for crossbreeding purposes at the lower altitudes. Consideration might also be given to the economics of the transport of feed from the lowland to the montane areas if feeds are going to be used more efficiently by temperate-type *B. taurus* breeds managed at the higher altitudes.

Under yard- or stall-feeding conditions, where cattle are purchased from breeders, it would appear probable that the higher the percentage of *Bos taurus* blood in the cattle the more they will respond to superior levels of nutrition. This could possibly stimulate crossbreeding as crossbred cattle would probably command a premium price.

As it has been recommended that the dairy industry in the tropics should mainly depend upon the use of crossbred cattle, bull calves and surplus heifers could be a useful source of beef animals for the feedlot industry. If these animals were collected and transported into areas of higher altitude they could be used for the production of 'baby-beef'. Crossbred dairy calves used for 'baby-beef' production should not be

Table 7.19 The montane areas in each continent as percentages of the total continental areas. (*Source*: Woytinsky & Woytinsky, 1953.)

Continent	Percentage total continental area by altitude		
	<153 m	153914 m	>914 m
Africa	10	65	25
Americas			
North	27	52	21
South	38	43	19
Asia	21	46	33
Europe	54	39	7
Oceania	23	75	2

castrated unless castration is mandatory in the country, as it has been shown that generally bull calves are 1012% more efficient converters of high nutrient content rations than are steer calves.

Where producers own small herds it would be necessary to organize and maintain an efficient artificial insemination service in order to produce crossbreds. It would also be desirable if the production and marketing of beef by small producers could be organized by an authority that would provide financial and technical services.

Disease and Parasites

It should be easier to control disease under intensive rather than under extensive conditions, but in general the problems are identical. There are, however, a few special problems associated with intensive management of beef cattle. Some of these are:

(1) Although cattle may not be grazing, tick control is still absolutely essential in non-tick-free areas and should not be neglected.

(2) Similarly, control of internal parasites is still essential, particularly in the younger animals, as many internal parasites may be brought into the yard on forage harvested from the fields.

(3) All classes of cattle are more likely to be subject to mineral and vitamin deficiencies when not managed on natural grazings. Special attention should be given to the feeding of minerals and to the possibility that the cattle may not obtain sufficient vitamin A.

(4) Baby-beef production provides special problems because of the nature of the feeding system. Cattle fed large quantities of concentrates and relatively small amounts of roughage are prone to digestive upsets, bloat and urinary difficulties due to the deposition of mineral salts in the urethra. In the temperate zone, cattle kept under these conditions are also specially prone to coccidiosis and to clostridium infections. It is not known whether this is also the case in the tropics.

Management and Feeding

Intensive management of beef cattle under grazing conditions is more or less similar to that of dairy cattle, and the intensity of operations of course depends primarily on the methods by which the pasture or fodder is managed.

There is ample information available in the temperate zone as to the most suitable feeds and methods of feeding and managing cattle indoors or in yards. To some extent temperate-zone experience may be used as a guide as to what may be possible in the tropics. It is recommended that readers consult Preston & Willis (1970) and Dyer & O'Mary (1972) for further information.

The most intensive method of yard or indoor feeding of beef cattle is where the cattle are fed high levels of concentrates for the production of baby-beef. The demand for meat of this type has expanded with the expansion of supermarkets and changes in consumer preference. Baby-beef has a bright red appearance and contains minimum quantities of fat and bone and maximum quantities of lean meat. It is usual to slaughter cattle that have been fed for the production of baby-beef at about 390410 kg liveweight, as above this liveweight feed conversion rates decrease.

The normal method of feeding is to give the cattle large amounts of grain which, in the tropics, could be maize, sorghum, rice, etc., plus a minimal quantity of good-quality hay or straw together with a protein concentrate, minerals and vitamins. Holsteins stall-fed this type of ration will grow at the rate of 1.6 kg per day. The grain used should be rolled, crushed or bruised, hay intake should be restricted to 0.91.8 kg per head per day after 12 weeks of age, and if silage is used instead of hay then the intake should be restricted to 1.8 kg dry matter per head per day. The protein of the concentrate ration should be of a type that will not rapidly break down in the rumen so that excessive nitrogen is not lost before utilization can take place. Water should always be provided *ad libitum*.

Except under very special circumstances, this type of feeding for beef cattle is likely to remain uneconomic in tropical countries until such time

as there is a large surplus of feed grains available. As previously stated, however, less intensive feeding of limited amounts of concentrates and/ or by-products might be economic under certain specific conditions.

Some new ideas on the use of sugar cane by-products in beef cattle feeding have already been discussed in the section concerned with perennial crop cultivation systems.

Molasses has been used for a long time in the liquid form as a supplement for beef cattle, and either alone or mixed with urea and minerals it can be absorbed into a cheap base such as bagasse and fed as a concentrate.

In the Caribbean it has been proposed that sugar companies could grow and dry elephant grass and use the milled meal as a base on which to absorb a molassesureamineral mixture. This idea would appear to have considerable merit and feasibility studies suggest that an excellent concentrate could be produced at a relatively low price. In East Africa some experimental work has been completed on the absorption of molassesureamineral mixtures on low-cost by-product feeds such as rice and maize bran.

Molasses may also be mixed with concentrates to provide additional energy and to act as a 'binder'. Attempts are also being made to dry and pellet molasses, but the technological difficulties are formidable.

In Jamaica rations for intensively managed beef cattle have been made from dried citrus pulp, dried brewer's grain and coconut meal, and experiments have been made in Colombia to evaluate the practice of fattening beef cattle on corn or sorghum silage and cottonseed meal. The wider use of urea or other forms of non-protein nitrogen such as diammonium phosphate in the feeding of intensively managed beef cattle has been explored. The utilization of these products was reviewed by Loosli & McDonald (1968). They stated that the available experimental evidence suggested that when fattening beef cattle were fed high-grain rations satisfactory results have been obtained where urea provided 25% of the nitrogen in the ration, but that at higher levels than this the palatability of the ration decreased, causing intake problems. They further stated that in the total ration the amount of urea should not exceed 1%.

Yards and Buildings

Where cattle are intensively managed in yards it is essential that the design of the buildings should be such as to save labour in feeding and handling and reduce heat stress on the cattle to a minimum. It should be emphasized that requirements are somewhat different in the dry as opposed to the humid tropics. Whereas in the dry tropics buildings should, in general, be oriented along an eastwest axis in order to reduce heat stress to a minimum, in the more humid tropics it is preferable to orient them along a northsouth axis in order to ensure that there is some drying out of the floor area on account of the sunlight travelling over the area of shade for some part of the day. It is also important to remember that water should always be available *ad libitum* in either the dry or the humid tropics.

Weaning

The intensive producer is not often concerned with weaning as he is usually not a breeder. However, in the case of producers in montane regions who are interested in baby-beef production, they should purchase calves that have been weaned at as early an age as possible and preferably those that are 56 weeks of age. At this age Holsteins, the preferred breed that could be available in montane areas, should weigh 6575 kg. Marking would normally be completed before the cattle are intensively fed.

Other Management Considerations

• *Castration*. Under feedlot conditions castration should be delayed as long as is legally possible, as bulls grow faster and produce leaner meat in the feedlot than do steers.

• *Dehorning*. Yarded animals should be dehorned.

• *Animal health practices*. Tick control is necessary in non-tick-free areas, although the frequency of operations can probably be radically reduced compared with that required on grazings.

Specific Requirements in the Tropics
Beef Enterprises

Few extensive or intensive holdings in the tropics are well planned. In general, very little attention has been paid to this aspect of cattle husbandry. On subsistence holdings the layout is usually completely haphazard.

Layout.

Unless there is a rational layout on extensive holdings it is impossible to maximize labour productivity or to be able to plan efficiently for future intensification. On intensive holdings a well-planned layout is required in order to maximize gains in productivity that are made possible by the use of improved pastures, genetically superior cattle and better overall pasture and animal management. The advantages of well-planned feedlots are obvious.

On large and small holdings the first step towards the attainment of an integrated and efficient layout is a master plan. This should not be sacrosanct but continuously updated in the light of experience and economic circumstances as the development of the holding proceeds. A survey plan is the ideal to use as a starting point for the master plan, but this is not often available. Aerial photographs can be of considerable assistance.

Roads and Drainage

On extensive holdings the building of roads may not be a major problem as fully formed roads are almost certain to be uneconomical and there is usually ample space to make a new track if the old one becomes impassable. However, a good all-weather access road is usually required to run from the entrance to the headquarters of the holding.

In hill country, drainage of roads need not be expensive as the roads can be strategically placed so that water runs away from them without the provision of expensive culverts. As far as is possible roads should be planned to run along ridges. Comparatively cheap ranch roads can be easily and rapidly built using a bulldozer or grader. It is usually desirable to have a perimeter track running inside the perimeter fence, if only to give access to the fence for repair purposes. Such a road can also act as a fire-break.

On intensive holdings in the humid tropics it is important that access roads should be usable during the wetter periods. It is better to build a road on top of an existing grass cover and raise the level above that of the fields and then use gravel or road metal for the surface. On intensive holdings a minimum road width between fences should be 5 m with access to every field for cattle and machinery. This can be achieved by offsetting the gates; a 3.5 m gateway is usually of sufficient width for cattle and machinery to pass.

Adequate drainage must be provided on both sides of roads on intensive holdings in the wet tropics. These should be waterways built so that they can be maintained using mechanical equipment.

Fencing and Shade Trees

On both extensive and intensive holdings expenditure on fencing normally represents a high proportion of the total capital expenditure. There is thus every incentive to plan and build fencing as economically as possible. The smaller and the more intensive the holding the greater the length of fencing required. For example, in a large square-shaped 900 ha holding divided into 6 paddocks, 0.023 km of fencing per hectare would be required, whereas on a small 30 ha holding divided into 30 paddocks 0.24 km of fencing per hectare would be necessary. Thus close fencing of the small farm would be ten times as expensive per unit area as limited fencing on the large farm.

The number of paddocks required on any holding will depend primarily on the type of management. In principle, the more numerous the paddocks the greater the flexibility in terms of intensity of stocking and the number of different classes of cattle that can be managed. Like all desirable objectives, however, subdivision can be

overdone. Little can be expected from additional subdivision beyond what is necessary for efficient grazing practice.

In arid areas the number of internal fence divisions may be very limited. Indeed it may be more economical to herd livestock than to fence. However, on extensive holdings in the humid tropics there is evidence to suggest that field size should be as small as is practicable. Square fields have the lowest fencing cost per unit area.

As cattle prefer to graze walking up steep slopes, fences running across the slope should be avoided.

Types of Fencing

Wire Fences

The price of wire is closely related to its weight. Provided it is sufficiently strong for the purpose envisaged, it is most economical to purchase wire that provides the greatest length for a given weight. Approximate lengths of wire per 45.4 kg weight are:

No. 8 gauge plain	462 m
No. 12 gauge barbed	425 m
12 1/2 gauge high tensile	1205 m

Barbed wire costs more per unit length and has a shorter life than plain wire. High tensile wire is most economical but is difficult to tie and has little elasticity; it requires particularly good strainer posts.

Staples used in fastening wires to wooden posts should be galvanized. All types of wire will last longer in drier areas. Wire in fences close to the sea will only have one-third of the life of wire on fences located inland.

Posts may be made of green timber, treated timber, concrete or steel, or live posts may be used. Some details of tropical timber trees that can be used for the manufacture of wooden fence posts are given in Table 7.20. In many parts of the tropics the cheapest posts will be those manufactured from treated, non-durable timber. Common preservatives are coal tar, creosote and pentachlorophenol. Full details of methods of

Table 7.20 Some tropical timber trees that can be used for the manufacture of wooden fence posts that will be somewhat resistant to termite attack. (*Source*: partly from MacMillan, 1952.)

Botanical name	Common name
Artocarpus heterophyllus	Jak-fruit
Artocarpus nobilis	Wild breadfruit
Balanocarpus maximus	Penak (Malaysian)
Bassia longifolia	
Berrya ammonilla	Trincomalee wood
Brachylaena hutchinsii	
Bridelia retusa	
Cassia siamea	
Casuarina equisetifolia	She-oak
Cedrela oderata	Cedar
Cedrela toona	Toon tree
Chloroxylon swietenia	Satinwood
Doona zeylanica	Doon
Dryobalanops aromatica	Sumatran camphor
Eucalyptus leucoxylon	Iron bark

Eucalytpus marginata	Jarrah
Eucalyptus robusta	Swamp mahogany
Eusideroxylon zwageri	Billion
Filicum decipiens	
Grevillea robusta	Silky oak
Hemicyclia sepiaria	
Hopea odorata	Thingam
Mesua ferrea	Ceylon ironwood
Mimusops hexandra	Palu
Myroxylon toluifera	Balsam
Pterocarpus marsupium	
Swietenia macrophylla	Mahogany
Swietenia mahagoni	Mahogany
Tamarindus indica	Tamarind
Tectona grandis	Teak
Terminalia glabra	
Thespesia populnea	Tulip tree
Vitex altissima	

This is a very limited list and the majority of species listed are found in Southeast Asia.

post preservation, of which there are several, are given by the Commonwealth Scientific and Industrial Research Organization (CSIRO, 1955). The life of treated posts varies according to the climatic environment.

Concrete posts are expensive to make, costly to handle and easily broken. They have the advantages of being fire resistant and long lasting. These posts can be made on the farm using a suitable mould. A 1.2 m high fence requires posts that are at least 1.8 m long and 15 × 15 cm in cross-section at ground level. Strainer posts should be at least 2.4 m long and 19 × 19 cm in cross-section. A suitable concrete mixture to use consists of one part of cement, two parts of sand, one part of clean shingle and one part of crushed rock. Reinforcing is essential, and four 0.6 cm diameter steel rods wired together at 46 cm intervals to make a frame is satisfactory. Thin bamboo may be used, but it is a poor substitute for steel.

The advantages of steel stakes are that they are easy to transport and to install, but they usually have to be imported and they easily rust. In order to minimize rust they may be painted with an asphalt-based paint.

Live posts are the cheapest, but their use is limited to the more humid areas. The great disadvantage of live fencing is high maintenance cost. They do have an added advantage that they can also be allowed to grow and act as shade trees and suitable species can also provide browse. Some useful common live-post species are detailed in Table 7.21.

The major points to note when erecting fences are:

(1) That the strainer post or strainer assembly must be well installed. If there is a distance of 100 m or more between strainer posts then these should be buried at least 1.2 m in the ground and held in position by 2.1 m long by 10 × 10 cm, in cross-section, stays.

(2) The intermediate posts should be exactly in line and well erected. For cattle it is normal to space the intermediate posts 5 m apart and they should be 1.2 m above ground level. In a five-wire fence the top wire should be 112 cm

Table 7.21 Some useful common live-post species.

Botanical name	Common name	Notes
Acacia mellifera	Namanara	Used in the Baringo District of Kenya
Aleurites moluccana	Candle-nut tree	
Aleurites trisperma	Balucanat (Philippines)	Will grow at altitudes up to 1000 m
Cieba pentandra	Kapok	Produces a useful cash crop
Dracaena menni	Asparagus tree	
Erythrina fusca var. *fastigiata*		Grows upright like a poplar in Pacific islands
Erythrina indica	Thorny dadap	
Erythrina lithosperma	Dadap	
Erythrina senegalensis		
Erythrina umbrosa	Ananca	
Eucalyptus spp.	Gums	Particularly in the montane tropics
Eugenia jambos	Roseapple	Also produces an edible fruit
Furcraea cabuya		Used at 30005000 m in Ecuador
Gliricidia sepium	Gliricidia	Will grow at altitudes up to 1000 m
Hibiscus tiliaceous	Gatapa	
Jatropha curcas	Physic nut	
Lannea nigritana		
Leucaena leucocephala	Wild tamarind; Ipil-ipil	Also cultivated for forage
Moringa pterygosperma	Horse-radish tree	
Pithecellobium dulce		
Pterocarpus indicus	Blue water tree	Vanuatu, Pacific islands
Sesbania grandiflora		A very useful forage tree
Spathodea campanulata	African tulip tree	
Spondias mombin	Spanish plum	
Sterculia foetida		Seeds yield a non-drying oil
Sterculia tragacantha	African tragacanth	

above the ground and the other wires spaced at 25, 25, 20 and 20 cm intervals. The top of the post should be 10 cm above the top wire. If it is a four-wire fence the wires should be 30, 30 and 25 cm below the top wire. If the distance between intermediate posts is more than 5 m then the fence must be provided with battens or droppers. The top of these should be more or less level with the top wire and the bottom at least 8 cm from the ground. Droppers can be made of wood, wire or strip steel.

(3) The wires must be kept tight and straight.

(4) The procedure should be first to erect the strainer post and stays, then to attach two plain guide wires to them, one at the top and one at the bottom. This should be followed by the erection of the guide posts and then the remaining intermediate posts should be installed. Finally the wires should be attached to the posts.

When a fence has to cross a steep gully it should be carried straight across from one bank to the other with the bottom wire just above the level of known floods. A swinging gate should be attached to the bottom of the wire that can close when the gully is empty, but rise with the flood water.

If posts are very expensive they can be spaced further apart and anchors or foots can be used in the fence instead of posts. These fences are known as swinging or suspension fences, and high-tensile wire should be used in their construction.

Stone Walls

These are common in the West Indies and in Hawaii and Samoa and are occasionally used in other parts of the tropics such as northern Nigeria. The advantage of a stone wall is the low maintenance cost. The disadvantages are the high initial cost of construction and the lack of skilled stone-wall builders. In Hawaii, dry stone walls are 0.91.2 m high and 0.91.2 m wide at the base.

Hedges

These are not at present generally used for enclosure in the tropics though they are common in some parts of East Africa and in some regions of the Americas and Southeast Asia. There are a number of suitable species (Table 7.22). Hedges have the advantage of low initial cost, but maintenance can be labour intensive and consequently expensive. This may be no disadvantage on subsistence farms in the humid tropics where available labour is often underemployed during some seasons.

Log Fences

When land is cleared a bush or log fence may be built. In the dry tropics thornbush laid in lines will make a stockproof fence that will last 2 or 3 years. These are common in the Sahel and savanna ecological zones in Africa. In the humid tropics a log fence can be built from felled trees, using a bulldozer during clearing operations. Fences of this type can be quite stockproof and may last from 2 or 3 to 10 years.

Electric Fences

These can be cheap to erect and are easily moved. The disadvantages of electric fences are that they need regular inspection and maintenance and are therefore only really useful on intensive holdings. There are two major types: the high voltage/high impedance and the high current/low impedance. The first type is used over short distances where cattle are rotationally grazed and the fences are frequently shifted. The second type is used for more extensive multi-wired fencing and is said to operate satisfactorily over quite long distances.

Field Gates.

Hanging gates can be made of wood, steel or aluminium or some combination of these materials. Provided it is well angle-braced a 1.2 m high hanging gate can be made 4.6 m long. If the gap is

Table 7.22 Some useful tropical hedge species.

Botanical name	Common name
For use in the drier areas	
Acacia modesta	
Agave americana	American aloe
Agave sisalana	Sisal
Caesalpina sepiaria	
Carissa grandiflora	Natal plum
Dodonea viscosa	Pichou
Euphorbia tirucalli	Milk hedge
Jatropha curcas	Physic nut
Opuntia dillenii	Prickly pear
Pithecellobium dulce	Madras thorn
Zizyphys spina-christi	Crown of thorns
For use in the wetter areas	
The majority of species listed in Table 7.21 as suitable for use as live-posts can also be used for hedges.	
Casuarina equisetifolia	She-oak
Duranta plumieri	Duranta
For use in the montane areas	
Aberia caffra (will grow up to 2500 m altitude)	Kei apple
Berberis arista	Berberry
Dodonea viscosa (will grow up to 2000 m altitude)	

longer than 4.6 m then additional support for the single gate must be provided from the top of the strainer post or two gates must be used.

Wire gates are cheaply constructed and quite satisfactory if they are properly constructed, but they are more tedious to open and shut (Fig. 7.51). An inexpensive 3.7 m pole and chain gate is illustrated in Fig. 7.51.

Shade

Shade trees are important in both the wet and the dry tropics. However, overall requirements for shade depend on the type of cattle utilized and the managerial policy. When a choice is made of the most suitable shade trees to use it should be possible to combine the provision of shade with the production of fruit, nuts, browse, firewood or saleable timber. Details of some suitable shade trees are given in Table 7.23.

Shelter Belts

These are not normally required at lower altitudes in the humid tropics, but may be of great utility in the drier areas and in the montane tropics. An ideal shelter belt consists of tall trees planted in the centre, surrounded by shorter species with shrubs or very small trees on the outside of these. Shelter belts should generally be planted at right angles to the prevailing winds and the species used should preferably possess a dense and evergreen foliage, a strong tough wood and be capable of natural regeneration from suckers or seeds. Recommendations with regard to some suitable species are provided in Table 7.24.

Water Supplies

The first essential is to estimate what the total consumption of water is likely to be on the

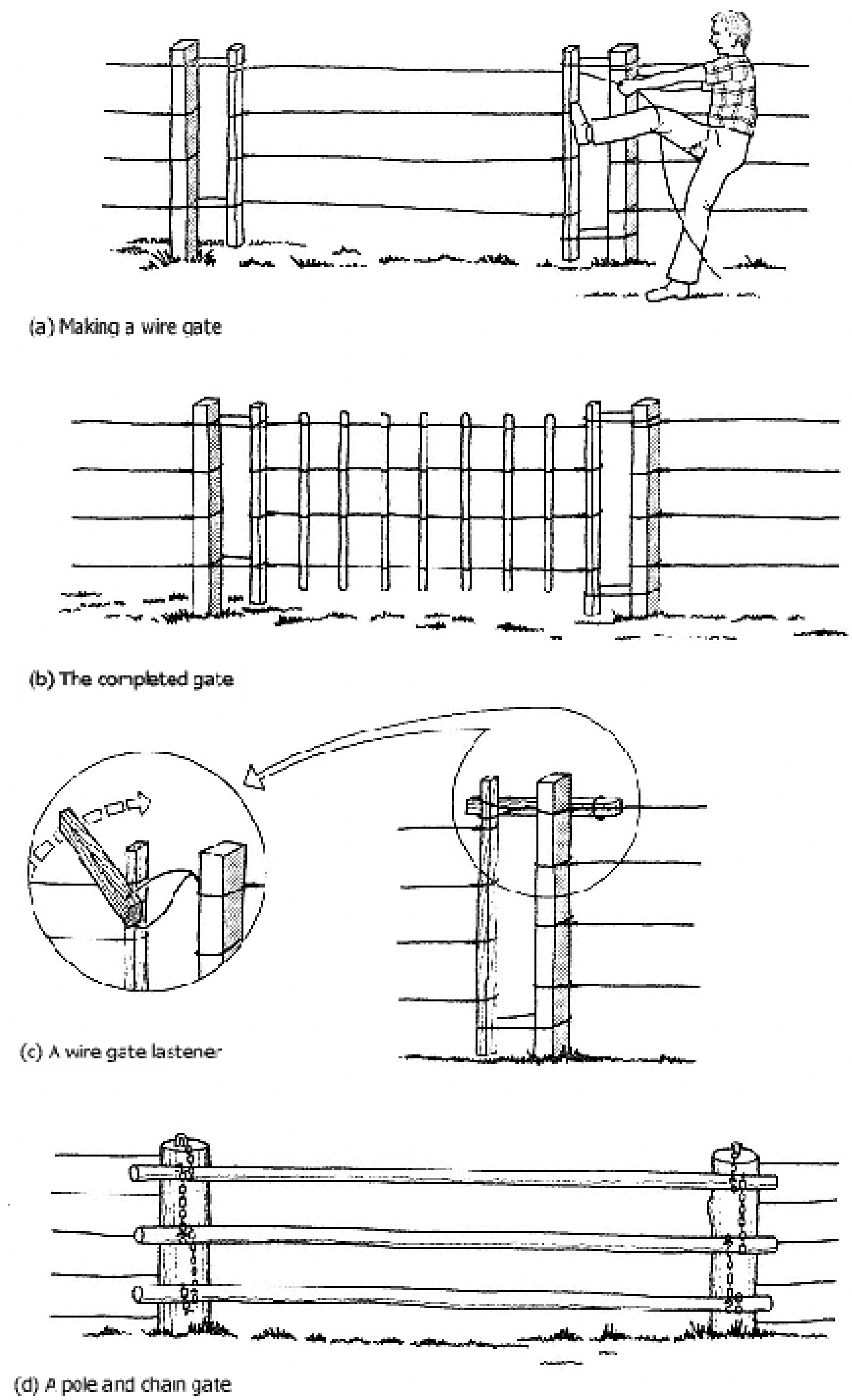


Fig. 7.51
Some details of wire gates and of a pole and chain gate.

Table 7.23 Some useful tropical shade trees.

Botanical name	Common name	Notes
For use in the drier areas		
Albizzia lebbek	Raintree	An evergreen that produces an excellent brown timber
Casuarina equisetifolia	She-oak	
Eucalyptus *alba*	White gum	
Eucalyptus citriodora	Lemon-scented gum	An evergreen that withstands drought and grows on salty soils
Ficus benjamina	Java fig	
Mangifera indica	Mango	Also produces a cash fruit crop
Melia azedarach	Persian lilac	
Phoenix dactylifera	Date palm	Also produces a cash fruit crop
Pithecellobium saman	Saman	Useful in the dry and humid areas; produces sweet pods that are an attractive feed for cattle
Prosopis alba	Algoroba	Produces pods that are relished by cattle
Tamarindus indica	Tamarind	Produces fruit and an excellent red-grained timber
For use in the more humid areas		
Anacardium occidentale	Cashew	Also produces a cash nut crop
Artocarpus altilis	Breadfruit	Also produces a food crop
Artocarpus heterophyllus	Jak-fruit	Will grow up to 2000 m altitude; produces fruit and an excellent timber
Chrysophyllum cainito	Star apple	Also produces fruit
Cocos nucifera	Coconut	Multi-purpose tree
Leucaena leucocephala	Ipil-ipil	A useful forage
Macadamia tetraphylla	Macadamia nut	Also produces a cash nut crop
For use in the montane areas		
Acacia dealbata	Silver wattle	This tree thrives from 1500 to 2000 m altitude; it produces a bark from which tannin is extracted
Acacia decurrens	Black wattle	
Eucalyptus robusta	Iron bark	
Eugenia jambos	Rose apple	Also produces an edible fruit
Grevillea robusta	Silky oak	This tree thrives from 1200 to 2200 m altitude
Tecoma leucoxylon	White cedar	

holding. Some details of average consumption of water by cattle are given in Table 7.25. Water for direct human and cattle consumption should be free from disease-producing organisms and should not contain excessive quantities of organic or inorganic materials and suspension or excessive dissolved mineral salts.

Water may be obtained from natural sources (rivers, streams, springs, rock holes and waterholes), from underground water resources (shallow and deep wells) or from catchment areas (roofs, rocky hills, field tanks and dams). A useful account of methods of exploiting water resources in Africa is provided by Edwards *et al*. (1983).

Natural Sources

The suitability of the water depends upon activities upstream or around the natural source.

Table 7.24 Some suitable tropical shelter-belt species.

Botanical name	Common English name	Preferred environment
Acacia dealbata	Silver wattle	Montane; >1800 m near the equator
Acacia decurrens	Green wattle	Grows on poorer soils than *A. dealbata* and *A. mearasii*
Acacia mearasii (synonym: A. decumens; var. *mollis*)	Black wattle	As *A. dealbata*
Andira inermis	Bastard mahogany	Lowland, humid
Bixa orellana	Annatto	Lowland, humid; useful when used with larger species
Cedrela serrulata		Montane; at medium altitude
Cinnamomum camphora		Montane; at medium altitude; humid
Eucalyptus spp.	Eucalyptus	Many species; one or the other suitable for lowland or montane; humid or dry; widely grown in montane areas
Eugenia jambos	Rose apple	Lowland: humid
Grevillea robusta	Silky oak	Montane; at medium altitude; dry
Pinus caribaea		Lowland
Pinus patula		Montane
Pinus radiata		Montane
Tamarindus indica		Lowland; dry to humid
Tecoma leucoxylon		Lowland

Table 7.25 Estimated daily water requirements of different classes of cattle in the tropics.

Class of cattle	Daily water requirements per animal (litres)	
	Wetter regions	Drier regions
Bulls	5065	5570
Calves	1832	2136
Dry cows, heifers and steers	50	55
Fatteners	65	70
Milking cows	6575	7585

Under range conditions 50% should be added to these allowances in order to offset wastage.

Springs should be fenced and the water run into a drinking trough. Cattle should not be encouraged to drink from rivers if the banks are steep.

Underground Water Resources

Shallow wells should be no less than 9 m deep and be sunk on a hillock rather than in a hollow in order to minimize surface pollution. It is preferable for the top of the well to be lined with brick, timber or brushwood. It is usual throughout many of the drier areas of Africa and Asia to construct shallow drinking troughs in clay alongside the wells (Fig. 7.52).

Deep wells are usually dug with drills whose maximum diameter is no more than 20 cm. They may be artesian or sub-artesian. Artesian water is often hot and must be cooled before being

Fig. 7.52
A typical shallow drinking trough made from clay.

used for drinking purposes. Deep wells are expensive and are often provided by a government authority. They should be closely controlled.

Catchment Areas

A major difference between field tanks or *hafirs* and dams is that tanks only collect catchment water and cannot be easily washed away, as they are constructed in depressions that may or may not have outlets, whereas dams catch flowing water and can be washed away by heavy rains unless they are properly constructed. Useful information on the construction of field tanks and dams in the tropical areas of Australia was provided by Beattie (1962), and in Africa by Edwards *et al*. (1983). Sandford (1983) noted how few of the dams built in East Africa since 1967 were still in use. They have silted up as there has been little or no maintenance. Workers at ILCA have shown that such dams can be easily maintained using simple animal-drawn scoops (Selassie & Cossins, 1985).

Water-Supply Systems

These may be classified as gravity, hydropneumatic and pneumatic. The choice of system depends upon local circumstances, specialized texts should be consulted for details of these systems.

Pumps

There are a multiplicity of types available and professional advice should be sought as to the most suitable pump to use in any specific location.

Reticulation Systems.

On extensive holdings or in nomadic or transhumant areas short lengths of pipe may be used to deliver water from a pump located at a river, stream, rockhole, waterhole, shallow or deep well or a tank or dam to watering troughs. Otherwise piped systems are not generally required. In the humid tropics under intensive conditions piped supplies may occasionally be justified. In areas where the water table is high and labour plentiful, such as the northern coastal regions of Colombia, it may be economic to sink shallow wells and provide hand pumps adjacent to each water trough. There is now a choice of galvanized and plastic pipe. The latter is less costly and cheaper to install.

Water Troughs

Water troughs can be constructed of galvanized iron, plastic or concrete. They should be sufficiently large to allow the cattle to drink freely without congestion. Circular and square tanks ensure that the maximum number of cattle can drink per unit length of the rim of the tank. The normal height of tanks is 3846 cm. As mentioned previously clay tanks can also be constructed. They are cheap to construct but usually only last one season. These usually have a rim of only 1523 cm above the ground (Fig. 7.52).

Buildings and Yards

Beef farms, whether extensive or intensive, usually only require handling yards and the minimum of buildings. Large holdings may require some buildings for offices, storage, etc.

Only handling yards and auxiliary equipment will be discussed in this text.

Handling Yards

These should normally be centrally located, on well-drained land where drinking water is available. Their location may of course determine their layout.

The size of the handling yard will be determined by the number of cattle that have to be worked at any one time. On very large holdings it is usually both more practical and economic to build several handling yards than to bring very large numbers of cattle to one very large handling yard.

Handling yards usually include assembly, holding, drafting and work yards, with forcing pens and crushes. Equipment may include a veterinary crush, a dip or spray and a weighing crush. There can of course be many and varied designs incorporating some or all of these features.

Whatever the design, there are certain considerations applicable to all. The most important are that the yard be located on land that can stand the constant wear of a multitude of cattle hoofs; that the containing fences be strong enough to withstand the shock of bunched cattle trying to break through and high enough to prevent a beast from jumping overto contain large, active zebu cattle the fence needs to be at least 1.7 m high in the main yards and 1.8 m high at the approaches and around the crush; and that the fences are free from projections which may cause damage to the cattle or to the workers.

Wire fencing is not suitable for such yards. Materials that are strong and that are seen to be strong, are needed. Substantial sawn timber, preferably hardwood, is satisfactory. Rails should be 20 × 8 cm sawn timber where the cattle are very large and are likely to be wild. Otherwise 15 × 5 cm timber rails can be used. Tubular metal is the ideal material if cost is of secondary consideration. Water pipe is usually available. In some areas, particularly where there are sugar factories, old boiler pipes may be obtainable. Concrete posts are not usually very satisfactory as under intense pressure they may snap at their junction with the ground. They are, however, sometimes used. Stone walls or other solid structures are objectionable, because they hinder the worker's movements and obstruct his sight, and they are usually uncomfortably hot to work in during daylight hours. Uprights should be no more than 2.1 m apart and be set at least 0.8 m in the ground. When 15 cm timber rails are used for a 1.7 m high fence, four are required. From the ground upwards these should be spaced at 25, 23, 23 and 36 cm intervals, the top of the top rail being 167 cm from the ground. With a higher fence an additional bar may be required.

The plan of a conventional yard designed to handle 100 head of cattle is shown in Fig. 7.53.

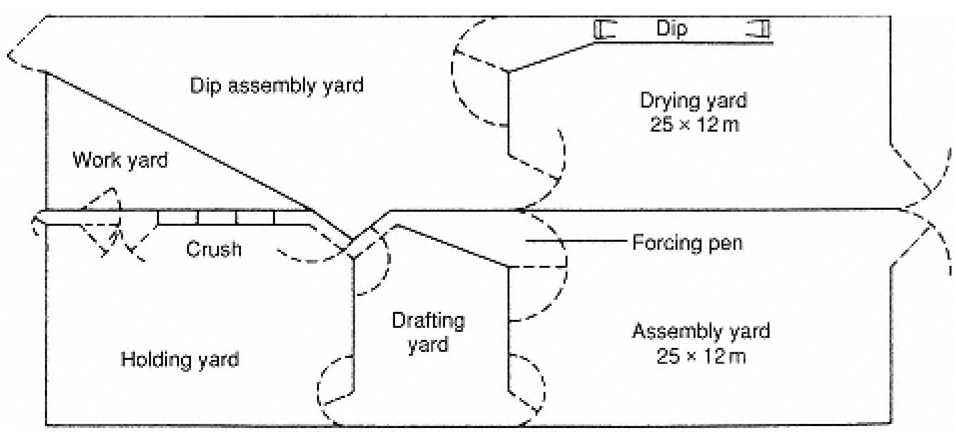


Fig. 7.53
Plan of a handling yard which will accommodate up to 100 head of cattle.

This type of yard has been found to be satisfactory when numbers of cattle have to be worked and quickly passed through.

Useful plans of different types of handling yards are described and illustrated in detail by Beattie (1962).

Cattle Crushes

The design essentials in a crush are that it should be sufficiently strong to restrain any cattle likely to be driven into it; that cattle should not be able to damage themselves while in it; and that it should provide the necessary facilities for handling the animals, using the minimum of labour.

A common fault in the design of crushes is to provide too much room for the individual animal. This encourages struggling, attempts to jump out and crowding up by one animal on the animal either in front or behind. It also makes any type of operation on the animal difficult, if not dangerous.

The average width of a crush for large tropical-type cattle should be no more than 70 cm, although the sides of the crush do not have to be vertical and it is desirable that the standing space in the crush should be narrower. Standing space does not need to be more than 53 cm wide. The height of the crush does not have to be more than 1.5 m. The length will depend upon how many cattle the operator wishes to retain in the crush at any one time. Five or six are a suitable number.

The crush may be constructed of tubular metal, sawn timber or roughly dressed timber. Tubular metal is most satisfactory.

The work to be done in the crush may take only a few seconds for each animal, such as in sorting, or it may occupy a longer period as when animals are inoculated. There are also occasions when the work to be done may take a considerable timeas in dehorning or in a veterinary examination. Thus the crush needs to be very versatile. When the holding time is short a holding arrangement is required that can be quickly applied or removed so that the flow of cattle through the crush is not impeded. At the end of the crush the control can be a 'drop' or sliding gate, while within the crush and between animals it can be single poles, somewhat wider than the crush and about 10 cm in diameter, slipped through brackets on the race or between uprights. These poles can be slotted in behind each animal in order to prevent them from moving backwards. This arrangement can effectively restrain cattle for a short period. For longer periods some form of head restraint is required.

The most suitable arrangement is to have what is essentially two types of crush in one unit. The type of crush described above would have a more elaborate holding arrangement at the exit end where the animal could be restrained by the head and body and where operative work such as dehorning could be conducted. The essentials of this section of the crush are a head restraint (a simple type which could be constructed by any small livestock owner with access to a minimum of tools is illustrated in Fig. 7.54), in lengths of no more than 2 m; some form of back restraint; and a hinged gate on one side (Fig. 7.55) that allows easy access to any part of the animal's body. Details of the design of a suitable crush of this type are shown in Fig. 7.56. It is possible to purchase manufactured standard crushes of this type that can be attached to the end of a locally built crush.

The whole length of the crush should be floored with concrete, and where practicable the concrete should be built up to a height of 0.6 m on either side of the race. This forms a supporting base for the uprights, a protection for the feet

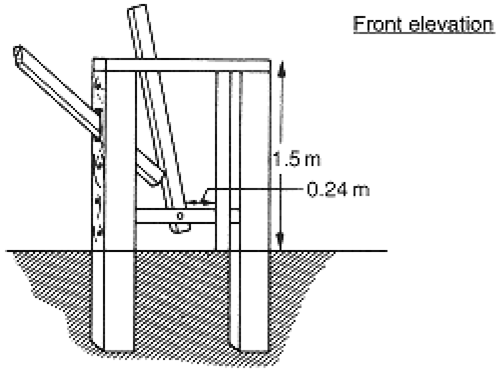


Fig. 7.54
A simple type of head restraint for cattle.

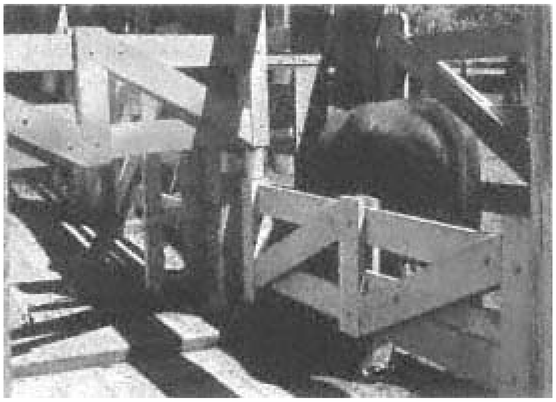


Fig. 7.55
Crush and walk through bail unit with a hinged gate.

and legs of the stock and a platform for the workers.

Buildings for Small-Scale Cattle Fattening

As stated previously small-scale beef fattening is conducted in certain specific areas of the tropics. The cattle are usually stall-fed in a hut, often in almost total darkness. Occasionally they are fed outside in small, shaded yards.

The walls of the hut are usually made of mud and the roof of thatch. A small space is left at the eaves for ventilation, but there are normally no windows, simply an open door. There is something to be said in favour of this primitive structure; it discourages flies, it effectively excludes direct exposure to the sun and reduces the inflow of hot air, it is conducive to rest, and while it restrains the animal it allows movement sufficient for comfort. Its chief defect is that by stopping practically all air currents it does not permit

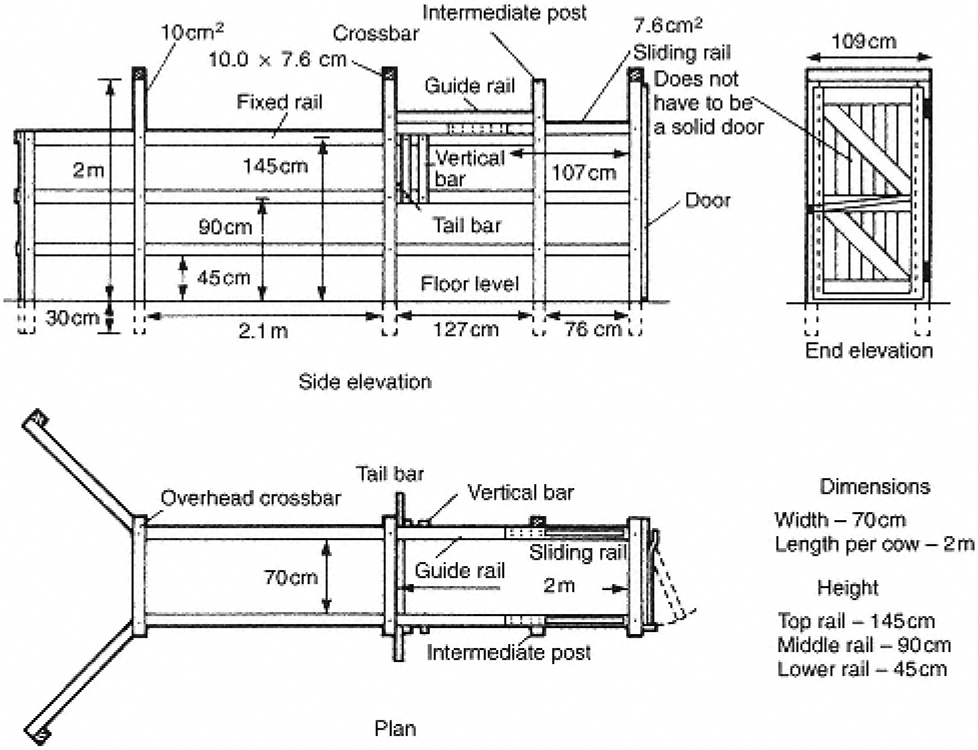


Fig. 7.56

Plan of a suitable cattle crush.

advantage to be taken of the very considerable relief they can afford to fattening animals.

The standing is insanitary, but accumulation of manure is an important sideline of the business and probably no other form of stable can so effectively promote the collection and decomposition of excrement and litter. A fattening ox produces about 4 t of solid manure and about 1.5 t of liquid manure per annum.

Defects of this simple type of building can be corrected by redesigning the walls so as to permit the free passage of air at all levels. Ventilating spaces can be opened at appropriate heights or, if the wall is made of brick, by leaving sufficient spaces it can be constructed in the form of a screen rather than as a solid wall. When timber is available, rough uprights spaced a few inches from each other can be substituted for the mud wall.

Such walls are satisfactory in a humid climate where there is no great difference in the temperature throughout the 24 hours; however, where there is a great variation between the maximum and minimum daily temperatures the solid walls are less objectionable than they might at first appear and are often preferable to semi-open ones. In any case, the roof, preferably thatched, should amply overlay the walls by a distance of at least 0.6 m.

The most economical size of such a building is one with a diameter of 3.7 m which will comfortably hold two mature bullocks of the larger breeds. If built of mud or sun-dried bricks, the wall should be 2.5 m high and at least 25 cm thick.

Feedlots

Feedlot design is a specialized operation. We suggest that interested readers should consult Preston & Willis (1970) and Dyer & O'Mary (1972). Space requirements for yarded beef cattle are given in Table 7.26. In all feeding yards

Table 7.26 The general space requirements of yarded (feedlot) beef cattle.

	Area of yard per head (m2)	Area of shade per head (m2)	Height of shade (m)
Earth yards			
Medium-sized yards holding <150 head			
Drier areas	7	2.54.5	3.03.7
Wetter areas	<37	2.54.5	3.03.7
		with concrete basea	
*Slatted floor houses*b			
Small yards holding <15 head	1.92.3		
Feeding troughs			
Length of trough per head: (on assumption that feed is always available)		15 cm	
Width of concrete apron in front of the feeding trough:		1.82.4 m	
Watering troughs			
Length of trough per 10 head: (on assumption that water is always available)		30 cmc	
In houses one automatic water bowl should be provided for every 1015 head			

a If the area below the shade is not concreted a larger shade area will be

required.
b If the slatted floor is in a yard and not in a building shade will be required.
c A concrete 'apron' is also desirable in front of the water trough.

of feedlots in the tropics, shade must be incorporated; approximately 3.7 m2 per adult animal is required. Water and feed troughs should be shaded.

Transport of Trade Stock

There are a few beef-raising areas in the tropics which are served with adequate transport facilities and seldom has the stockowner a choice of how his cattle should be conveyed to market; they might, however, go by one of four ways, namely, on the hoof, by road, by rail or by air.

Movement on Foot

Cattle which are almost continually on the move in search of food should not be much inconvenienced by moving in one direction for the same distance as they do on their feeding range each day. Thus it might be thought that droving would in all circumstances be the most economical way of moving livestock. For short distances it undoubtedly is, but over long distances such a categorical statement cannot be made because many considerations are involved.

Droving may well be the least expensive method when an adequate supply of food and water can be arranged at suitable points along the route or when a herd can be watered night and morning, and where during the interval it can move at leisure from one post to another while grazing on the way. These ideal conditions are seldom found, at least after the herd has joined the main route. On these tracks feed soon becomes scarce, particularly in the dry season, and as one drove follows another it well-nigh disappears. For a time feed can be obtained by skirting the tracks, on land where there is no objection to roving, but such grazings eventually lie too far away to permit their use if the cattle are to make a reasonable rate of progress to their destination. More often, the owners of the land in the vicinity of the track will not permit grazing.

As well as these reasons why trade cattle must be kept to a well-defined track, there is one other, i.e. the danger that the wandering cattle may spread contagious disease in the country through which they pass. As long as they are kept to defined routes it is possible for the authorities to check their health from time to time, to control disease if it should appear and to give protection to those in danger. As a controlled, danger-free, unimpeded passage of trade cattle through a country may confer as much benefit to the general community as it does to the owners and because they are often a necessity, trade routes are usually the concern of governments.

Ordinarily it is the location of water which decides how the route will run and also the rate at which the stock will move along it. Where watering points are plentiful, movement is at the discretion of the drover, but where they are located at long intervals, he has no choice but to cover the distance before extreme thirst decimates his stock. For the cattle to travel under such stress results in serious loss of liveweight which, in West Africa has at times been estimated to be as much as 50%. In West Africa, as in other regions of Africa, cattle which have successfully traversed country where scarcity of water is the hazard have to face another danger in the form of a 'tsetse-fly belt' through which, if they are not protected, they must pass very quickly. Even under more favourable conditions in other parts of the world, a shrinkage of up to 20% of liveweight is common and 1015% would be accepted as normal. Only mature cattle are fit to undergo long journeys on foot under these conditions.

Indigenous cattle can manage fairly well when water points are located 2025 km apart, but in many countries that is not possible. Intervals of over 30 km have to be accepted and sometimes a 2-day journey separates water points. If finished cattle are not to suffer serious liveweight shrinkage water should be available at no more than 8 km intervals, and there should be facilities for grazing or for obtaining conserved forage *en route*. This statement is particularly valid for any temperate-type or crossbred cattle.

The supply of feed offers almost as great a problem as that of water in certain seasons of the year. In localities where a satisfactory fodder reserve can be accumulated at each post for the feeding of trekked cattle, 5 kg per head will allow

the cattle to continue trekking and the route to be kept open, but it will not prevent the cattle losing weight.

The loss from death which may be expected on a given route is unpredictable, but depends chiefly on the prevailing cattle diseases and the weather, and upon what facilities are afforded to withstand them. Where beef is acceptable in any condition, much of the loss to the owner is avoided by emergency slaughter and sale of the meat at a village or township along the route.

Transport on hoof entails loss from shrinkage, loss from death as well as drovers' pay, taxes, tolls and extortions.

Rail Transport.

Over long distances rail transport effects saving on maintenance and handling changes, tolls and other incidental expenses as well as on shrinkage and deaths. Loss from shrinkage under the worst conditions of rail transport may be as high as 10%, but should normally range between 3 and 5% on a journey of up to 72 hours. That does not, of course, take into account losses arising before entrainment. Loss from bruising may be considerable. It has been observed in Kenya that rail transport resulted in down-grading of some 78% of carcases and that it could be greatly reduced as the data in Table 7.27 indicate. It would appear from these observations that a single-sex group of polled, indigenous cattle that were provided with bedding would suffer the least bruising.

Railway trucks which are to carry livestock should be roofed, provide for free passage of air and have battened or non-slip floors. If they are not designed for end-to-end loading they should have movable partitions to facilitate side loading and to help cattle to keep on their feet while the train is moving. Cattle should be packed in a truck close enough to prevent them being thrown about during transit. They should be grouped so that those of approximately the same size and condition are trucked together. Horned cattle should be secured by their horns to the truck side; they should stand head to tail so that alternate animals face in the opposite direction.

The stock should be watered every 2427 hours and, when practicable, should also be fed at these intervals. On journeys of more than 3 days' duration, offloading of the cattle for feed and rest should be compulsory, for humane reasons and to prevent undue loss in body weight.

At the railhead, arrangements must be made for watering, feeding and resting the stock before subjecting them to the rigours of a train journey under tropical climatic conditions. If grazing is not adequate and accessible, a supply of forage must be made available for hand feeding. A minimum of 9 kg of forage per head per day is desirable. Water should also be freely available in troughs, whose approaches and surroundings

Table 7.27 Incidence of bruising in cattle transported by rail.

	Bruising Observed	Bruising Not observed	Total cattle	Percentage with bruising
Horned cattle	271	378	649	41.8
Polled cattle	28	111	139	20.1
Exotic cattle	176	118	294	59.9
Indigenous cattle	152	239	391	38.9
Bedding used	82	156	238	34.5
Bedding not used	454	223	677	67.0
Sexes mixed	78	206	284	27.5
Sexes not mixed	83	548	631	13.2

should be able to withstand constant trampling and wear. The minimum requirements for water would be 23 litres per animal per day.

Where a large number of cattle are regularly loaded a reception yard with crush and sorting facilities should be constructed of a size suitable for the number of cattle expected at any one time. The sorting pen should lead to pens sufficiently large to hold one truckful of cattle, and these to loading pens, which in turn should lead by a ramp, with a gradient of not more that 1:2, to a loading platform on a level with the floor of the truck. These yards should be built according to the specifications given for cattle yards in a previous section. Discarded rails or sleepers make very suitable material for yard construction. If additional horizontal rails are added to the lower half of standard cattle yard fences so that there is no more than a 13 cm gap between rails, the yards can be used for the holding, sorting and loading of small stock as well as cattle.

Animals should not be loaded more than 1 hour before the rail journey commences.

Road Transport

As stated in a previous section transport of stock by road is increasing very rapidly in many tropical countries. The major constraint is a lack of all-weather roads. For example, in the western savanna region of the Sudan, a major cattle-producing region, there are at present few all-weather roads between the Nile and Tschad border. Consequently, cattle are still mainly trekked to Khartoum, very limited numbers being transported by rail. Unformed roads are not only liable to be impassable during the rainy season but the maintenance of vehicles is so costly that livestock transport becomes prohibitively expensive, and in addition the cattle are likely to be badly bruised, or even more seriously hurt, during transit.

The advantage of transporting cattle by road, where there are all-weather roads, is obvious. The cattle can be loaded at the farm or at the holding yard out on the range and directly transported to their destination without serious shrinkage loss.

Air Transport

This method of transporting live animals is too expensive to allow for its use in the marketing of fat cattle. It is, however, a method that is growing in importance for the transport of breeding cattle from one country to another. Under special and specific conditions, such as occur in Borneo, Malaysia, it is also an economic method of transporting meat.

Beef Quality

It is impossible to define a universal standard of beef quality. Consumer preference, that depends to some extent on a specific cooking culture, may vary from country to country, or from one social class to another within a country. It can also gradually change within a country or a social class in accordance with a change in economic circumstance or the dictates of fashion. For example, in most Western industrialized societies, until comparatively recent times the production of high-quality beef required a well-finished carcase with a high fat content. However, consumer preference has changed and present demand is for lean beef with a minimum fat cover, although with some fat within the muscle or 'marbling'.

The contrasts in consumer preference occurring in the tropics are typified by the differences in consumer demand in Southeast Asia and East Africa. In Southeast Asia very lean meat is required and beef from *Bibos* spp.-type cattle is preferred where it is available. On the contrary, fat meat is still demanded by the majority of African consumers in East Africa, and carcases possessing a degree of fatness unacceptable to the Southeast Asian consumer are considered to produce quality meat and are highly prized.

A major difference between consumers in most industrialized societies and those in most tropical countries is that the latter prize offals and consider them to be of high quality, whereas consumers in the industrialized societies eat less and less offals and generally consider them to be of inferior quality to carcase meat.

Recently, the incidence of bovine spongiform encephalitis (BSE) in cattle in the United Kingdom and some regions of Europe has further reduced the consumption of offals in industrialized societies.

In most tropical countries the average consumer still demands fresh meat, as chilled and frozen meat is unacceptable. This preference has certainly delayed rationalization of the livestock and meat-marketing systems in many countries. If fresh meat is demanded by the consumer then killing usually takes place during the night, the fresh meat being available in the market by dawn and retail sales being completed early in the morning.

In the Philippines, where some of the major beef-production areas are located far from the major centres of consumption, attempts to rationalize the beef industry by siting abattoirs close to the production areas and shipping chilled beef to the major consumption centres have not been very successful. There has been very considerable resistance to this innovation as the majority of indigenous consumers wish to see the meat that they purchase 'twitching' on the market stall. They consider that under these circumstances it is fresh and cannot be contaminated.

Although the ageing of beef is considered essential in Western societies, as this process improves tenderness, aged beef is often regarded with suspicion in Southeast Asia as it tends to possess the same colour as buffalo beef. Southeast Asian consumers have no aversion for buffalo beefindeed they are major consumers of this commoditybut they expect to pay a lower price than they would for cattle beef. Hence it may be difficult to sell high-quality aged beef.

Despite the present major differences in consumer preference from country to country it can be assumed that as tropical countries industrialize and urbanize, and under the stress of economic and technological change, preferences will slowly change and become more uniform.

It is likely, however, that in the long term acceptable beef quality will be equated with that type of meat that the beef industry can produce most economically and that can be used in the food culture practised by the consumer. This means that there are always likely to be some differences between different communities in their definition of quality in beef, but that gradually chilled, frozen and processed meats will become more generally acceptable to tropical consumers and that beef quality will be more or less generally equated with leanness and tenderness.

The policy of imposing Western, and in particular American, meat-grading standards in tropical countries is thus of very doubtful value. It could even be a retrogressive action. This does not mean that upgrading standards of some kind are not required, but they must be equated with the average consumer's concept of quality meat requirements. The evolution of grading standards in most tropical countries will take time, and considerable investigation of the carcase attributes of locally produced cattle and average consumer preferences will be necessary.

Dairy Farms

When a new dairy farm is planned the buildings should be sited as far as is possible in the centre of the holding. This ensures that outdoor-managed cattle walk a minimum distance to and from the paddocks and that forage cut in the field for indoor-managed cattle will be transported minimal distances.

A road with a hard surface is required between the perimeter fence and the milking bail, but internal roads can be constructed of soil, although in the wet tropics they must be well drained on both sides and raised somewhat above the field level or else they are likely to become quagmires. The internal dirt roads should be narrow in order to facilitate the droving of stock, but if the farm is mechanized the road and gateways must be sufficiently wide to allow the operation of tractors equipped with trailers. The road can be relatively narrow even on mechanized farms as long as the gateways are offset.

The farm should be well drained and ditches should be fenced on both sides to prevent their destruction by stock. Double fencing is obviously expensive, but it does have the advantage that shade trees can be planted between the fences so that while the trees are young and vulnerable they are protected from the cattle.

The grazing area should be divided into as many paddocks as is economic. In the wet tropics paddock size should be no more than 0.81.2 ha and preferably smaller. In drier areas the economic paddock size can be much larger. A minimum of 14 separate paddocks is required for proper rotational grazing purposes in the wet tropics, although more are desirable. The cheapest type of fence to erect is probably a live fence, although the maintenance costs of such a fence are usually considerable. Some details of common species that can be used to provide 'live posts' are shown in Table 7.21. A four-wire fence is suitable for the enclosure of dairy stock and only the top wire needs to be barbed. The cheapest uprights for a wire fence will probably be termite-resistant, indigenous hardwood posts, but creosote-treated softwood posts, if available, may be almost equally effective. Concrete and/or steel uprights are usually too expensive to utilize. Some details of species providing suitable timber for fence posts are given in Table 7.20.

Water should be provided in all paddocks if this is practical and economic. It should be possible to devise a fencing layout that allows for one water trough to serve two, three or four paddocks. If water cannot be provided in all paddocks it can perhaps be made available in the field roads that serve a number of paddocks and, of course, at the milking bail.

Shade trees should be planted around all paddocks and along all roads. It should be possible to select species that not only provide shade but also nuts, fruit, browse, timber or firewood. Details of suitable species are given in Table 7.23.

Buildings

The type and number of buildings required will depend upon the managerial practices. If dairy cattle are managed indoors or indoorsoutdoors a number of different buildings will be required, while if the farm is medium to large in size considerable equipment and machinery will need to be housed. Details of the general space requirements in the tropics of different classes of dairy cattle are given in Table 7.28.

Dairy stock managed indoors may be housed, fed and milked in the same building, they may be housed in one building and fed and milked in another, or they may be managed in loafing yards and milked in a separate building. If dairy stock are managed outdoors, only a milking bail and an associated milk room and feed store are required for the milking cows, but other buildings will also be needed such as housing for the small calves and storage space for feed, seeds, fertilizer and machinery.

A building in which milking cows are housed, fed and milked is generally known as a dairy barn. The temperate-region type of enclosed dairy barn is not recommended for use anywhere in the humid tropics, but a well-ventilated version could be used in the semi-arid tropics, particularly during the very hot months.

Dairy barns are of two types: single or double range. The double-range barn is more economical for the housing of herds of more than 16 to 20 milking cows. Double-range barn standings can be designed so that the cattle face inwards onto a central feeding passage or outwards with feeding passages on either side of the building (Fig. 7.57). It is generally considered that the latter arrangement is more desirable. A building with the same basic plan (Fig. 7.57) but with no solid walls is suitable for use in the humid tropics. The roof of such a building should have a very wide overhang in order to provide the maximum shade and to prevent the incursion of heavy rain. The floor should be constructed of concrete, and left with a rough finish in order to prevent cows from slipping. The standings should be constructed of tubular steel, heavy bamboo or hardwood and the mangers of glazed pipe, if this material is available. If not, specially treated concrete or wood may be used. Water should be available for the cows in every standing, preferably from automatic water devices. If sprinkling or misting equipment is used, with or without fans, adequate drainage must be provided.

Table 7.28 The general space requirements of different classes of dairy cattle.

Class	Type of construction	Space requirement
Milking cows	*Milking stalls (barn)*	
	Width: single stall	1.03 m
	double stall	1.98 m
	Length: small breed	1.37 m
	large breed	1.52 m
	Length of feeding manger per cow	0.76 m
	Height of floor of stall above dunging passage	0.150.18 m
	Width of feeding passage	0.911.22 m
	Milking stalls (bail) used with line machine	
	Width of stall	0.76 m
	Width of bail	0.60 m
	Collection and dispersal yardsarea per cow	
	Polled cattle	2.3 m2
	Horned cattle	3.7 m2
	Loafing yards	
	Total area per cow	6.57.4 m2
	Shade area per cow	3.75.6 m2
	Length of feeding manger per cow	
	Access at all times	0.300.46 m
	Limited access	0.610.76 m
	Loose boxes for calvingarea per cow	1516 m2
Bulls	*Bull houses*	
	Area within house per bull	17 m2
	Area outside house per bull	3437 m2
Calves	*Individual pens for small calves*	1.83 × 1.22 m
	Collective pens: area required	
	Calves up to 3 months of age	23 m2
	Calves 36 months of age	3 m2

Cow Cubicles

These may be used for housing dairy cattle where they are fed and milked in a separate building. Cubicles reduce bedding costs and are useful in areas where bedding materials are expensive. They give the animal complete freedom of movement so that they stay cleaner, lessening some of the chores at milking time. This type of housing is, however, suitable only in a semi-arid environment or in montane areas.

Loafing Yards

These do not need to be elaborate structures. They can be concrete, gravel or dirt yards with provision for shade, feeding and watering and the removal of manure. In the wet tropics concrete or gravel yards are essential as even the best-drained earth yards become quagmires. Elsewhere a rammed earth yard will suffice unless sprinkling or misting equipment is installed, when it is essential to provide concrete

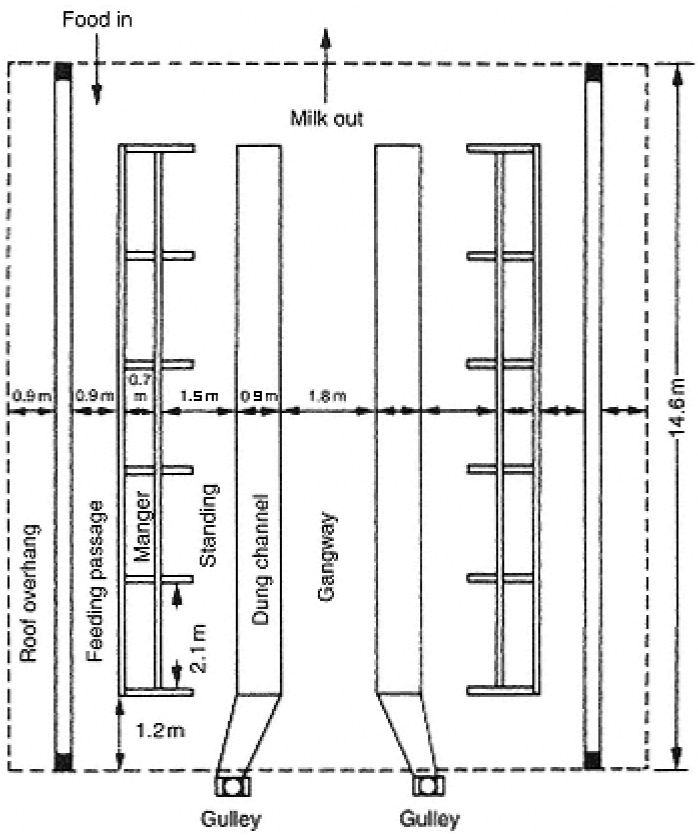


Fig. 7.57
Plan of a typical double-range dairy barn suitable for housing medium sized cows: with open walls in the humid tropics.

yards with adequate drainage. Shade must be adequate. Water can be provided from automatic devices or from troughs. There should be a number of separate yards for the segregation of milking cows, dry cows, heifers and bulls. The yards may be laid out rectangularly or in a semi-circle. There are advantages and disadvantages in both layouts. Feeding and manure removal can easily be mechanized in yards of this type. In very large units the disposal of manure may present problems. Where adequate supplies of water are available concrete yards can be washed down and the resulting effluent pumped or run on to the grazings. In Florida one enterprising feedlot operator, confronted with this problem, is using the manure to produce methane gas and then to culture chlorella that will ultimately be fed back to his cattle. These methods of manure disposal should be seriously considered by large-scale dairy farmers who practise an indoor managerial system in the wet tropics.

The Milking Shed, Bail or Milking Parlour

This is the building used specifically for milking, required by dairy farmers who practise either indoor or outdoor management. A milk-holding room, feed store and assembly and dispersal yards are usually associated. The parlour does not require walls, only a roof with a substantial overhang. If the assembly and dispersal yards are equipped with water sprays or misters they must be built with concrete or some other type of sealed floor and if cows have to stand for any period in either yard some form of shade and drinking water must be provided.

A number of different layouts are possible and although all can be used for either hand or machine milking, the more elaborate have been specifically designed for machine milking. The most common layouts used are:

(1) Abreast walk-through parlours that can be single- or two-level

(2) Herring-bone parlours

(3) Two-level tandem, walk-through parlours

(4) Roundabout parlours when very large herds are milked.

In the tropics an abreast, walk-through type is the most convenient for the small dairy farmer and is probably the easiest and cheapest to construct. The other types are only likely to be used by larger dairy farmers. A choice of type by these must depend on local circumstances and, in particular, on the availability and cost of labour and the availability of suitable machines, spares and maintenance services.

A plan of a four-stall, single-level, abreast, walk-through type of milking parlour is shown in Fig. 7.58. Where a releaser machine is used the stalls should be 0.7 m and the bail 0.6 m wide,

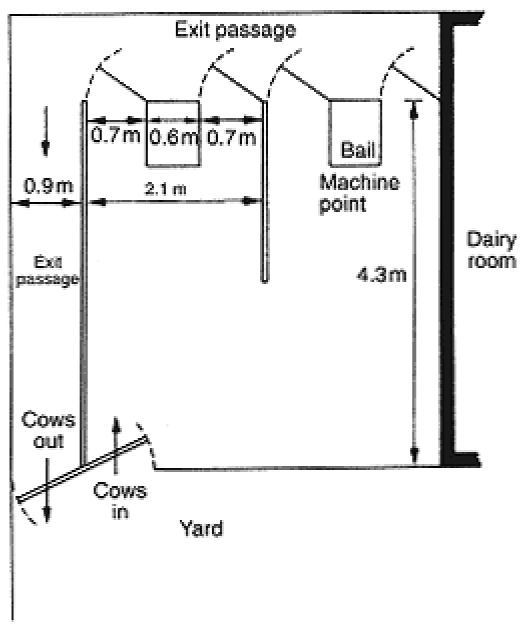


Fig. 7.58
Plan of a four-stall, single level, abreast type of milking parlour.

whereas when a bucket milking machine is used or hand milking is practised the stalls should be 1 m wide. It is usual to have one milking machine unit at each bail, so that one cow can be milked while the cow on the other side of the bail is being washed. Cold and/or hot water should be on tap at the bail for washing purposes and concentrates can be fed at the bail in a feeding box. Concentrate feeds can be measured out either by hand or by using automatic feed-measuring devices. A two-unit system is the economic minimum. It is considered that for up to a total of 15 cows a bucket machine is the most economic to use in this type of milking parlour, whereas with more cows a line-type of releaser machine is more economic. The floor should slope away from the bails both in front and behind the cows. The two-level, abreast, walk-through type is a variant where the milker works at a lower level than the cows stand. It does not possess any outstanding advantages over the single-level type.

Details of herring-bone, tandem and roudabout types of milking parlour can be found elsewhere. Roundabout milking machines can be of the tandem or herring-bone layout. A rotating platform slowly carries the cows around. Each cow is milked in the time that it takes for the platform to revolve once. As cows which have been milked leave the platform, replacement cows step on. In this way the milking process is continuous and rapid. Readers with a particular interest in milking parlours should consult a dairy extension officer or a representative of a commercial organization concerned with the building and equipping of dairies.

Milk Room.

This is needed whether the cows are hand or machine milked. If the cows are hand milked or milked with the aid of a bucket machine all that is required is a small room adjacent to the milking parlour. It should be designed so that it is easy to clean and can be screened in order to keep out insects and should be sited on the side from which the prevailing wind blows and on the other side from the feed store. Milk will be strained and cooled in this room in preparation for sale either to a factory, a wholesaler or through a retail channel. Milk-cooling equipment of some type is necessary and if it is economically feasible this should incorporate refrigeration. Cold and/or hot water should be available as should utensil washing and draining facilities. If the cows are milked using a line-releaser milking machine, the milk room should be sited at the end of the line as it will house the releaser and associated equipment.

Feed Store

The size of the feed store will vary according to the size of the dairy unit, the types of feed used and the type of equipment utilized. All feed stores, even the smallest, should be constructed so that rodents can be excluded and they can easily be fumigated to destroy weevils and other insect pests.

Dairy Cattle Yards

These do not have to be so stoutly constructed as beef cattle yards. Details of the space requirements for yarded cattle are given in Table 7.28.

Equipment for Milking

The dairy farmer who milks by hand requires only a minimum of equipment; seamless milking pails, washing buckets, teat cups for testing for mastitis and a stool. If milk production is recorded, a simple milk-weighing scale is also necessary. The majority of small dairy farmers in the tropics do not even possess this minimum of equipment. The aim of dairy extension services in tropical countries should be to assist the small dairy farmer to acquire this minimum of equipment and to teach him/her to use and clean it properly.

Considerably more equipment is required for machine milking. There are two main types of milking machine: bucket and line-releaser. The tendency has been for the line machine to increase in popularity as it requires less labour, but as stated in a previous paragraph it is probably most economic to install a bucket machine if 15 or fewer cows are milked.

The essentials of a milking machine are as follows: a vacuum pump to create the vacuum required; a vacuum tank; a vacuum line to the individual sets of teat cups; a method of collecting the milk and a pulsator. Vacuum pumps can be of several types and may be operated by an electric motor or by a small internal combustion engine. It is essential to see that there are no leaks in the vacuum system. The normal teat cup is made of metal or plastic and has a rubber inflation or lining. Two types of inflation are in general use: the ordinary rubber liner which collapses and closes under the teat, and the moulded inflation that collapses around the teat and so never obstructs the flow of milk. The pulsator is a device that produces an intermittent vacuum, causing alternate compression and release of the cow's teats through the action of the rubber liner or inflation in the teat cup. First a stimulus is applied to the teat to ensure that the milk is let down and secondly the teat is massaged in order to maintain circulation of the blood. Milking without pulsation causes the teats to swell, makes the cow uncomfortable and thus impedes the let-down of milk. There are several different types of pulsator.

The quality of milk obtained by machine milking depends upon the care taken in cleaning and operating the machine. If the machine is properly cleaned, then the milk will certainly be of as high a quality as that produced by the best hand milking. Milking machines and other dairy equipment may be sterilized by the use of steam or chemicals. Milking machinery acquires a deposit known as milkstone on the metal and rubber parts and fat is absorbed into the rubber. Milkstone is a deposit consisting of milk solids together with mineral constituents from the water used in washing the machine. It increases the tendency of the rubber to crack, reduces the efficiency of the rubber rings and harbours bacteria. Fat absorption causes rubber to lose many of its qualities when exposed to light. As a consequence milking machinery must be particularly well cleaned. Line-releaser machines can be fitted with automatic washing equipment and these are recommended for use in large dairies in the tropics where labour is often unskilled.

The dairy farmer in the tropics requires a machine that is simple in construction and operation, that needs the minimum of cleaning and that is easily cleaned by relatively unskilled labour. Machines that fit these specifications have been available for several decades. A milk-flow measuring device can be fitted that indicates to the milker when milking should be ended and stripping begin, and this device has been found to be particularly suitable for use in the tropics where milkers are often relatively unskilled.

Equipment for the Milk Room

Straining

All milk should be strained immediately after milking is completed. Special strainer pads are the most efficient and hygienic to use for this purpose as they can be discarded after use. However, any type of suitable cloth can be used as long as it is frequently changed and thoroughly washed and sterilized after use.

Cooling and Refrigeration

As soon as the cow has been milked the bacteria in the milk start to multiply. Immediate cooling of the milk reduces bacterial multiplication very drastically. In Table 7.29 details of the relationship between temperature and the bacterial count of milk 12 hours after milking is shown. Some bacteria produce chemical changes in the

Table 7.29 The relationship between temperature and bacteria count in milk.

Temperature (°C)	No. bacterial per ml (000)
4.4	4
7.2	9
10.0	18
12.8	38
15.6	453
21.1	8 800
26.7	55 300

composition of milk, the most common being the formation of lactic acid from lactose or milk sugar. This causes the normal souring of milk. As ambient temperatures are always high in the tropics milk sours easily and quickly unless it is cooled or boiled. Boiling will kill the bacteria but must be carried out before the concentration of lactic acid in the milk has risen too high.

Thus, if fresh milk is to be distributed in the tropics it should, if possible, be cooled at the farm and then pasteurized or sterilized either at the farm or at a central processing plant.

The proper cooling of milk at the farm is a very difficult problem as most tropical dairy farmers possess few cows and cannot afford refrigeration even if power is available for this purpose. One solution would be the use of a cooling tower, commonly used on dairy farms in Queensland in the past. This equipment depends upon the evaporation of water having a cooling effect on a second supply of water that can then be used in a milk cooler (Fig. 7.59). Another possibility is the use of solar water coolers, but the technology for this type of equipment is not yet well developed and in any case the initial capital cost of a solar cooler is likely to be too high for utilization by the peasant farmer. The only practical solution at the present time is rapid collection of the milk from individual farmers and cooling at a central collection depot.

In dairying areas where power is available and the dairy farms are of a sufficient size, collection can be made by road tankers, the farmer storing his milk from both daily milkings in a refrigerated vat until such time as collection is effected.

Separation

When, for any reason, milk cannot be sold in the fresh, liquid state it is generally desirable to remove the cream from it. The latter may then be used for the manufacture of butter and/or ghee and the skim-milk can be used for human consumption, for livestock feeding or for the manufacture of a variety of dairy products.

Fat can easily be removed from the remainder of the milk by reason of the fact that it rises to the surface by operation of the force of gravity.

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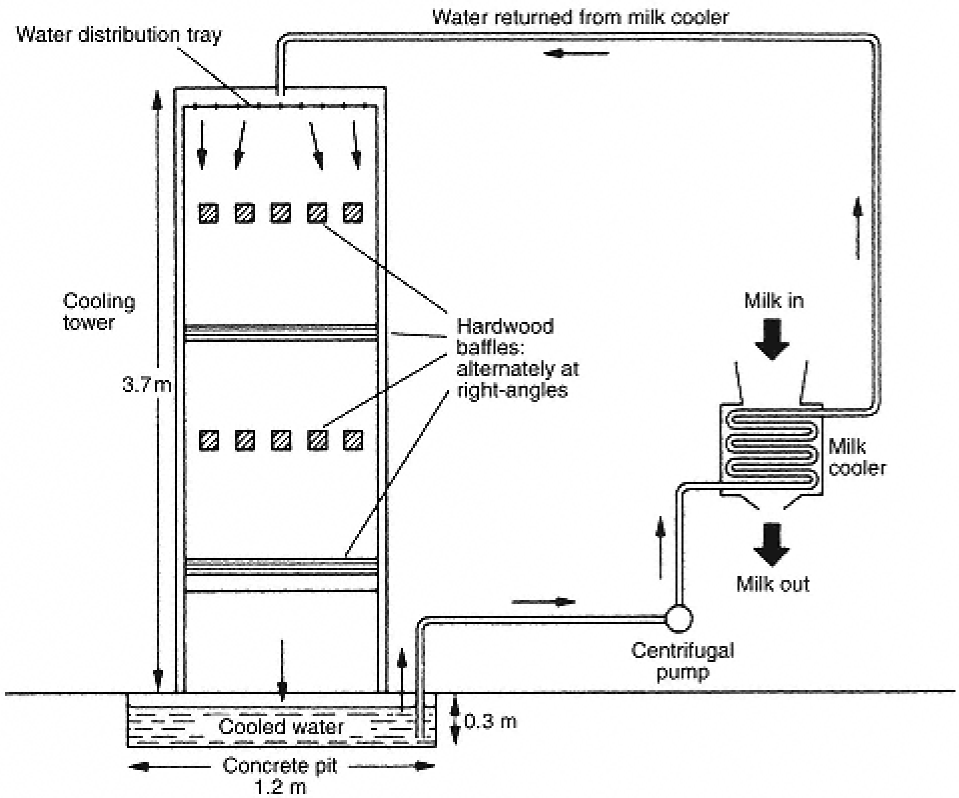

Fig. 7.59
Schematic layout of a Queensland-type evaporative milk cooler.
(Source: Few, 1946.)

This occurs because fat is lighter than skim-milk, 1 ml of fat weighing 0.9 g while 1 ml of skim-milk weighs 1.036 g.

There are three major methods of accomplishing the separation of fat and skim-milk. These are described below.

The Shallow Pan Method

Milk is placed in a shallow pan approximately 10 cm deep for a period of 2436 hours. The major part of the fat rises to the top and the cream is removed using a skimmer. The remaining skim-milk usually contains 0.51.0% butterfat.

The Deep Pan Method.

Milk is placed in a pan 50 cm deep, and after standing for several hours the cream is removed using a dipper. Sometimes the milk is diluted with water before being placed in the pan, as it is claimed that dilution lowers the resistance of the milk fluid to the rising milk fat globules. This is a more efficient method of removing butterfat than the shallow pan method, but if it is to work really satisfactorily the deep pan should stand in a bath of cold water. This is often not a practical proposition on small farms where there is no refrigeration.

Mechanical Separation

This is accomplished by applying centrifugal force to the milk. When milk is spun rapidly in a container the force of gravity is increased by about a thousand times so that a difference of 0.136 in the specific gravity of butterfat and skim-milk at rest becomes a difference of 136 as the milk is spun. As a consequence the fat separates very rapidly from the skim-milk towards the

centre of the container in which it is being spun. Arrangements then have to be made to remove the fat separately from the skim-milk. Dispersing the milk in the container into thin sheets facilitates separation and all modern milk separators incorporate a series of inverted, cup-like discs inside the bowl, each kept slightly apart. Mechanical separators are now made in almost any size, farm separators usually being made in a range designed to process 45450 litres of milk per hour.

Useful Data for Cattle Producers
Estimation of Body and Carcase Weight

Very experienced cattle dealers and butchers can judge the probable carcase weight of live cattle with astonishing accuracy by sight, but such ability is not at the command of the average stockowner. Unless the latter has some guidance his estimate of liveweight is a guess which may be very wide of the mark.

Certain body measurements when properly applied give an indication of livewight which is remarkably accurate. One formula that is used is

$$LW = \frac{L \times G}{300}$$

where *LW* is the liveweight in pounds, *L* is the length from the point of the shoulder to the pin bone in inches and *G* is the chest girth in inches.

Estimates made using this formula for zebu cattle weighing 136408 kg have seldom been wrong by more than 10% and have usually been correct to within 5%. Using this formula liveweights are more often under- than overestimated.

It is not always easy to make accurate measurements of either the length or the chest girth of cattle, even if they are quiet. In taking these measurements it is desirable that the animal should not drink or eat for 12 hours, and should stand with all four legs squarely under the body with the head held in the normal position. In chest girth measurements the tape should be passed around the body immediately behind the shoulders, at the smallest circumference, and pulled up so that it fits tightly to the body.

In India it has been recommended that when the above formula is used to estimate the liveweight of steers it should be modified as follows:

$$LW = \frac{L \times G}{Y}$$

where *Y* is 9.0 if *G* is less than 165 cm, 8.5 if *G* is between 165 and 203 cm and 8.0 if *G* is greater than 203 cm.

Bennett (1951) derived a formula for estimating the liveweight of steers whose chest girth varies from 160 to 203 cm. It is as follows:

$$LW = 1.04\ (27.5758 \times G\ ) - 1049.67$$

When the liveweight is known, an approximate estimate of the dressed carcase weight can be made according to the 'condition' of the live animal. The dressed carcase weight of very fat animals ranges from 62 to about 65%; that of animals in good condition from the better indigenous breeds from about 54 to 56%; and that of indigenous animals in poor condition from 50% downwards. The *Bos (bibos)* spp. breeds must be exempted from this general statement. Even when they are not fat they possess a high carcase dressing-out percentage.

Using temperate-type *Bos taurus* cattle Bennett (1951) derived the following formula for calculating the dressed carcase weight:

$$DCW = 44.08 - (0.0029 \times LW) - (0.115 \times h) + (0.2658 \times g) - (0.0801 \times b)$$

where *DCW* is the dressed carcase weight in pounds, *LW* is the liveweight in pounds, *h* is the height in centimetres, *g* is the chest girth in centimetres and *b* is the belly girth in centimetres.

It is not known whether this formula can be used for estimating dressed carcase weight of the steers from indigenous tropical breeds.

Dentition of Cattle As an Indicator of Age

The eruption of each pair of teeth takes place at approximately the same time of life and thus an indication of an animal's age may be obtained by an examination of its teeth. As far as cattle are concerned, the indication is a very approximate one, because differences in age of as much as 16 months may be found in cattle with teeth at the same stage of development. Differences of this degree are unusual, but an allowance must be made for a variation of up to 6 months.

The front teeth of cattle are easily examined and it is therefore to them that attention is generally confined, the stage of development of the molar teeth being noted only when further confirmatory evidence is required. On each side of the lower jaw there are four incisors or front teeth and six molar teeth in the adult bovine. In the upper jaw there are the same number of molars but no incisors.

Many factors influence dentition, the chief of which are breed and the standard of nutrition on which the animal has been reared. There is a very marked difference between the ages at which the teeth are erupted in cattle of the early-maturing breeds of temperate origin and the late maturing breeds of the tropics. There is also a difference, but a less marked one, between breeds of tropical cattle and groups within the breeds which have been raised on different kinds and amounts of food. In addition there are individual variations at least as great as the average between groups which cannot be specifically accounted for.

Lall (1948) collected information, submitted by government-farm staff who examined Indian cattle, grouped according to their breed and recorded age. Because of the method used and because on some farms births were recorded only according to the quarter of the year in which they occurred, no exactness can be claimed for the data collected. The information he received referred to most of the important Indian breeds. Lall considered that the data provided, shown in Table 7.30, approximate to the average closely enough to be of practical use.

In tropical Africa recorded observations are few and refer only to a small number of cattle. The usual individual and breed differences were noted, but the average of the groups recorded by

Table 7.30 Average age of cattle at eruption of their permanent teeth. (*Sources*: aLall (1948); bKikule (1953) and Joubert (1956); cMiller & Robertson (1943).)

Type of teeth	Age (months)			
	Indigenous Indian cattlea	Indigenous African cattleb	Ranched American cattlec	Purebred British cattlec
Incisors				
First	2430	28	24	21
Second	36	34	3036	27
Third	48	41	42	33
Fourth	5460	49	5460	39
Molars				
First	24		24	24
Second	24		24	24
Third	36		33	33
Fourth	6		6	6

Fifth	18	1215	1215
Sixth	24	21	21

two observers (Kikule, 1953; Joubert, 1956) are very similar. The average ages at eruption of the permanent incisors of cattle of African breeds are also shown in Table 7.30.

Observation of the ages at eruption of the permanent incisors of 78 White Fulani reared on a high plane of nutrition in Nigeria indicated that the average quite closely approximated those of mixed East African Shorthorn Zebu and Ankole at Entebbe, Uganda, but there were several individuals far removed from the average.

The corresponding data for 'highly bred stock' in the United Kingdom and for ranch cattle in the United States (Miller & Robertson, 1943) are also shown in Table 7.30.

When examining the teeth of cattle there may be some difficulty in deciding if the four pairs of front teeth are old, temporary or permanent ones, but if there are six molars at each side of the jaw this confirms that the front teeth are permanent.

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8
Buffaloes

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History, Origin and Distribution

The domestic or water buffalo (*Bubalus bubalis*) belongs to the family Bovidae, subfamily Bovinae, genus *Bubalus* and species *arnee*. Its relationship with other Bovinae such as cattle and bison is shown in Fig. 7.1. Although the American bison (*Bison bison*) is sometimes referred to as buffalo, this is a misnomer. The bison belongs to a separate subgenus of the Bovinae. There are four wild species of buffalo but all existing types of domestic buffalo appear to have been derived from *Bubalus arnee*, the wild buffalo of mainland Asia. Information on origin and the precise period of domestication of the buffalo is lost in antiquity. The crescent horns, coarse skin, wide muzzle and low-carried heads of buffaloes represented on seals struck some 5000 years ago in the Indus valley suggest, however, that the buffalo had already been domesticated in the Indian sub-continent around that time. The domestication of swamp buffaloes took place independently in China about 1000 years later. The movement of buffaloes to other countries, both eastwards and westwards, is thought to have occurred from these two countries.

Buffaloes were unknown in Egypt during the time of the Pharaohs. Their movement to Egypt took place via Iran and Iraq when Arabs took these animals from India during the first invasion in the ninth century. Water buffaloes were later introduced into Europe by pilgrims and crusaders returning from the Holy Land in the Middle Ages.

Importation of buffaloes to other countries in Southeast Asia, Western Asia, Europe, Australia and South America followed, the spread being slow and gradual. However, attempts at the introduction of these animals into some countries did not meet with success. The Earl of Cornwall, a brother of Henry III, brought buffaloes to England, but the animals did not thrive (Cockrill, 1967). Introduction of the buffalo into African countries south of the Sahara has not so far been very successful. At present attempts are being made in Australia to redomesticate the feral buffaloes. The results achieved so far are encouraging.

Buffaloes have been introduced into more than 20 countries in Latin America, particularly into Brazil. The importations have primarily been from India, Italy, Bulgaria, Indochina and Australia, the latter contributing rather small numbers. The first introductions are believed to have been made in 1890, but subsequent importations have mostly been of the breeds from the Indian sub-continent. Initially they were introduced for work and later for meat. They were primarily managed on ranches on extensive systems, but presently milk production is in high focus, and the dairy-type breeds are stall-fed and properly housed in barns and kept under intensive management. The breeds of Indian origin are maintained as pure breeds, but they have also been interbred leading to new breeds like Brazil Mediterraneo and Brazil Murrah.

All types of domestic buffaloes (*Bubalus bubalis*) are generally grouped as river and swamp buffaloes. As the name implies, the water buffalo, whether of the river or the swamp type, has an inherent predilection for water and loves wallowing in water or mudpools. The river buffalo, as a rule, shows preference for clean running water, whereas the swamp buffalo likes to wallow in mudholes, swamps and stagnant pools. Buffaloes are good swimmers.

Buffaloes are generally easily domesticated. The African buffalo (*Syncerus caffer*) which was believed to be difficult to domesticate could be tamed easily when scientific efforts at domestication were made (Rouse, 1970). On the other hand domestic buffaloes, both of swamp and river types, can easily revert back to semi-wild or wild state if let lose to fend for themselves, as has happened in northern Australia.

Buffaloes do not cross with cattle or vice versa.

World Population and Production

The water buffalo is found only in certain regions of the world (Table 8.1). The distribution of the buffalo is conspicuous by its being confined principally to the areas where animal husbandry is poorly developed and badly organized. By and large, buffaloes are owned only in small numbers by resource-poor farmers. In fairness to buffalo stockowners in these regions, it may be stated that they maintain buffaloes not from ignorance of the potentialities of other large ruminants but because they find that in the prevailing agricultural situation no other domestic animal will thrive like the buffalo and at the same time be so useful and economical.

According to the FAO (1995) (Table 8.1), the total population of buffaloes in the world during 1994 was over 148 million. Twenty-two countries of Asia accounted for 96.55% of this population, of which India alone accounted for 53%. Europe accounted for less than 0.3%, Africa 2.2% and Latin America a little over 1 %. The total buffalo population of the world is steadily increasing, although a declining trend can be noticed in European countries except in Italy where an increase by 400% has been registered since the 1960s.

The river buffalo constitutes around 65% of the total world buffalo population and accounts for 92% of the total milk produced. India alone contributes 42% of total milk produced by buffaloes. The major concentration of the river buffalo is in India (78 million), Pakistan (18 million) and Egypt (3.3 million). India possesses the largest number of buffaloes (53%), followed by China (15%), Pakistan (13%), Thailand (3%), and Nepal (2%). Indonesia, the Philippines, Vietnam, Egypt, Myanmar, Turkey, Sri Lanka, Iraq, Iran and other countries account for the remaining 14% of the population. The largest concentration of swamp buffaloes is found in rice-growing countries of Asia. Taking the buffalo population of 1961 as a base, the population (up to 1994) increased at the rate of 54, 182 and 113% respectively in India, Pakistan and Egypt (Table 8.1). The corresponding increase in milk production was 26, 13 and 14.3%, respectively.

The buffalo renders invaluable service to mankind by way of work and the supply of milk and manure while alive, and meat, hide, horns, hooves, bones, etc., after death. There are large areas where human survival is dependent on this animal. In spite of these facts, the study of buffaloes has remained neglected. The benefits of science and technology have hardly impinged on the husbandry of the buffalo population to enable a fuller expression of its production potentialities to be achieved. The greatest handicap to its development lies in very large gaps in our knowledge of the physiology of the animal, disease prevalence in the species and the husbandry practices most suitable for animals located in widely varying environmental conditions. Of late, scientific workers in countries such as India, Egypt, Pakistan, Thailand, etc., have been studying the animal in depth with a view to evolving efficient buffalo husbandry techniques, and as a consequence considerable information is now accumulating. Available published material is still, however, very scanty and what is published is often fragmentary and incomplete and sometimes contradictory.

Table 8.1 World distribution of buffaloes. (*Source*: FAO, 1995.)

Continent country	Numbers (000) 1961	1994	Percentage increase or decrease 19611994	As percentage of world total in 1994
Africa				
Egypt	1 501	3 200	113.1	2.15
Americas				
Argentina		3	100.0	0.002
Brazil	63	1 600	2 439.6	1.08
Columbia		1	100.0	0.000
Cuba		2	100.0	0.001
Ecuador		2	100.0	0.001
Paraguay		3	100.0	0.002
Peru		4	100.0	0.002
Surinam	0	1	100.0	0.000
Trinidad & Tobago	5	9	80.0	0.006
Venezuela		25	100.0	0.017
Total	68	1 650	2 326.4	1.11
Asia				
Azerbaijan	0	10	100.0	0.007
Bangladesh	500	874	74.8	0.587
Bhutan	3	4	33.3	0.002
Brunei	14	10	-28.5	0.006
Cambodia	520	829	59.4	0.070
China	8 368	22 416	167.8	15.06
Hong Kong	2	0	-100.0	0.000
India	51 208	78 825	53.9	52.97
Indonesia	2 861	3 512	22.7	2.36
Iraq	250	100	-60.0	0.0672
Iran	247	300	21.4	0.201
Kazakhstan	0	105	100.0	0.070
Laos	420	1 308	211.4	0.879

Malaysia	345	186	-46.0	0.124
Myanmar (Burma)	1 049	2 130	103.0	1.43
Nepal	795	3 176	299.4	2.13
Pakistan	6 700	18 887	181.8	12.69
Philippines	3 452	2 630	-23.0	1.76
Sri Lanka	772	870	12.6	0.59
Syrian Arab Republic	1	1	-0.0	1.767
Thailand	4 964	4 257	-14.2	2.86
Uzbekistan	0	85	100.0	0.057
Vietnam	2 205	3 009	36.4	2.02
Total	84 676	143 524	69.4	96.45
Europe				
Albania	7	2	-71.4	0.001
Belarus	0	20	100.0	0.013
Bosnia Herzegovina	0	1	100.0	0.000
Bulgaria	191	17	-99.9	0.011
Georgia	0	20	100.0	0.013
Greece	71	1	-98.5	0.000
Italy	18	92	411.1	0.061
Macedonia	0	1	100.0	0.000
Romania	184	0	-100.0	0.000
Russian Federation	0	140	100.0	0.094
Turkey	1 140	116	-8.9	0.111
Yugoslavia Federal Republic	0	19	100.0	0.012
Total	1 611	429	-73.3	0.288
World total	87 856	148 803	69.3	

The buffalo has the ability to efficiently convert coarse feeds like straws and agro-industrial by-products into milk and meat. Therefore, in countries in which plants are the major food source of a large human population, the buffalo will continue to play a significant role in meeting the animal protein requirements of the population.

General Characteristics

Buffaloes are big-boned, rather massive animals with the body set low on strong legs with large hooves. Dewlap and hump are absent. The body frame of a good milk-type river buffalo conforms to that of dairy-type cattle, and that of the swamp buffalo to that of draught breeds of Zebu. Horns are generally more massive than those of cattle. They are broad, flat and almost rectangular in cross-section near the base and with prominent ridges across the long axis. Swamp and several breeds of river and nondescript buffaloes have backswept horns. Two of the milk breeds of river buffaloes have very tightly curled horns. Some buffaloes have fantastically long horns that may measure more than three-quarters of the total length of the body.

At birth and during early calfhood buffaloes have a good coat of soft hair but the hair becomes sparser and coarser as the animal grows, depending on the breed, season and housing practices. In some adult buffaloes the body is practically bare. The hair is black, dun, creamy yellow, dark or light grey, or white. Some breeds show white markings in the form of stripes and some others are conspicuous in having a piebald coat.

Star, blaze or socks and a white switch at the end of the tail are frequently found in river buffaloes. Among swamp buffaloes white animals are not uncommon. The incidence varies in different areas and appears to be the result of selections based on local beliefs and superstitions. The incidence is relatively low in Borneo (Indonesia), China and Taiwan where there is a prejudice against such animals, but in Bali and parts of Thailand more than 15% of buffaloes are white as these animals are considered auspicious.

Hair whorls of swamp buffaloes are characteristic and distinctive, and could be used as an important means for identification of an animal. The colour of the skin varies from jet black to light pink. The skin may be unpigmented in localized areas, black or slate-grey being the most common in dark-coloured animals. Leucoderma (a condition in which the skin and/or hair becomes white) is known to occur in buffaloes. The aetiology of leucoderma is unknown and the disease does not affect production in any manner.

The sheath of the male swamp buffalo adheres close to the body except at the umbilical end. In the river buffalo the sheath is more pendulous and is somewhat similar to that of zebu cattle. There is no tuft of hair at the preputial opening in the buffalo. The scrotum of the male buffalo, both of the swamp and the river types, is much smaller than that of male cattle of similar size. In the swamp buffalo there is no constriction near the attachment of the scrotum to the abdominal wall, but a distinct neck can be seen in the river buffalo.

Among the river buffaloes a few welldefined breeds with standard qualities and with specific physical characters that differentiate them unmistakably from other types can be found only in India, Pakistan, Italy and Latin America. These are all milk breeds, but their number forms only a very small fraction of the total buffalo population in these countries. The vast majority of buffaloes are nondescript. These vary greatly in size, weight and general features. These animals are the product of centuries of indiscriminate breeding without any selection criteria.

In Russia, development of a breed of buffaloes commenced in 1935 in the Caucasus. These Caucasian buffaloes were given a breed status in November 1970. This is a dual-purpose breed with good meat and fairly satisfactory milk qualities (Agabeili *et al*., 1971).

Breeds.

The domestic water buffalo is classified into river and swamp types. They belong to the same species but have different habitats. The swamp buffalo has 48 chromosomes and the river buffalo has 50. They interbreed and produce fertile hybrid progeny. The disparity in chromosome numbers has not been explained so far. The swamp buffalo is mainly a draught-cum-meat animal which has sweptback horns and is found principally in Eastern Asia. The river buffalo usually has curled horns and is found in Western Asia, Brazil, Russia, Italy and some East European and Central Asian countries. It prefers clean water, rivers, irrigation canals and ponds to wallow. This type is docile and has specially been developed for milk production with high fat content in the Indian sub-continent.

Some of the well-known milch breeds of river buffaloes are Murrah, Nili-Ravi and Surti in India, and Nili-Ravi and Kundi in Pakistan. The Egyptian, Iraqi and Italian buffaloes also have high potential for milk and are derivatives of this subgroup. Some other breeds of the milk type found in India are the Jaffarabadi, Bhadawari and Mehsana, primarily used for milk and work and classified as dual-purpose.

Brief descriptions of some of the important breeds of buffalo are provided below.

Indian

Bhadawari

The home tract of this breed is Bhadawari estate, part of Bah Tehsil in Agra district and the adjoining areas of Gwalior in India. These animals are usually copper coloured. The hairs on the body are scanty, black at the root and reddish brown at the tip. The legs from hoof to knee and hock are usually brownish white. The tail switch is white or black and white. The horns are flat, compact, growing backward and then upward, turning inward with slightly pointed tips. Animals are medium-sized with a wedge-shaped body. The head is comparatively small, bulging out between the horns. The forehead is slightly broad and deep in the middle. The dewlap is absent. The chest is well developed. The barrel is short but well developed with short and stout legs having black hooves. The tail is long, thick and flexible. The udder is not so well developed. The testes are of medium size though not of uniform length. The fat percentage of milk is very high (13%). Males are usually used for draught and can stand heat better than the other breeds. The average adult body weights of females and males are 386 and 476 kg, respectively.

Jaffarabadi

This breed is found in the Gir forest of Kathiawad in Gujarat State, India. It is named after the town of Jaffarabad and is also called Bhavanagri or Gir. The colour is usually black. The horns are heavy and broad, sometimes covering the eyes; are inclined to droop on each side of the neck and turn up at the points into an incomplete coil. The forehead is very prominent and bulging. Animals are massive and long barrelled. The body is long but not compact. The head and neck are massive. The dewlap is well developed. Average adult weight of males and females is 590 and 454 kg, respectively. Butterfat percentage of the milk is high.

Kundi

The word *kundi* means fish-hook in the Sindhi language. Ware (1942) first described Kundi as a distinct breed while admitting that some breeders still consider it a geographical type of the Murrah. The Kundi breed is distributed in the forest tract along the River Indus, in the rice-growing region of north Sindh and in the swampy and rice-growing tracts of Karachi and Hyderabad districts of Pakistan.

Kundi animals are generally jet black (85%), although light brown are not uncommon (15%). Horns are thick at the base, inclined backward and upward, and end in a moderately tight curl.

The forehead is slightly prominent. The face is hollow and eyes are small. Hindquarters are massive. Mammary glands are capacious with prominent milk-veins; teats are squarely placed. Kundi buffaloes are smaller than Nili-Ravi with females weighing 320450 kg.

Mehsana

The home tract of the Mehsana buffalo lies in the Mehsana district of Gujarat State, India. The Mehsana breed has been derived from crosses between the Murrah and the Surti. Individuals show a wide variation in appearance and colour. Animals are black or brown/fawn with white markings on the face, legs or tip of the tail. The horns vary from coiled to sickle in shape. The Mehsana has a longer body than the Murrah, lighter limbs, and longer and heavier head. The chest is deep with a broad brisket. The shoulders are broad and blend well with the body. The legs are medium to short in length. The barrel is long and deep with well sprung ribs. The tail is medium thick and long. The udder is well developed and well set. The teats are fairly thick, long and pliable. The Mehsana females have the reputation of being persistent milkers and regular breeders. The average mature weight of males and females are 569 and 430 kg, respectively.

Murrah

The breeding tract of this breed extends over the entire north-west of the Indian sub-continent. These animals have long been selected for milk and curled horns. The resulting breed was named Murrah, meaning curled.

The animals are massive, stockily built with a short broad back, and light neck and head. The horns are short and tightly curved. The udders are well developed. The hips are broad, and foreand hindquarters are drooping. The tail is long, reaching to the fetlocks. The colour is jet black with white markings on tail, face and extremities. The body weight of an adult female is 430500 kg and that of a male, 530575 kg. The body length in adult male and female is around 1.5 m. The height and heart girth in males (1.5 and 2.3 m) are slightly higher than in females (1.4 and 2.2 m).

Nagpuri (Ellichpuri)

The home tract of this breed is Nagpur region of Maharashtra State and the adjoining areas of Andhra Pradesh and Madhya Pradesh of India. The animals are usually black although white patches are often found on face, legs and tail. The distinguishing feature of the breed is long, flat, curved horns carried back on each side of the neck, nearly to the shoulders. The face is long and thin. The neck is somewhat long. The limbs are lighter and the tail is comparatively short, reaching below the hocks. The average weight of an adult male is 522 kg and that of a female is 408 kg. This is a dual-purpose breed.

Nili-Ravi

Earlier authors (Handa, 1938; Oliver, 1938) referred to the Nili and Ravi as strains of the Murrah which differed little from it, except in geographical location, i.e. the Sutlej and Ravi river valleys, as distinct from Rohtak, Karnal, Gurgaon and Delhi for the true Murrah. However, in 1938 Nili was shown as a breed at the First All-India Cattle Show and after the second and third shows, the Nili and Ravi were briefly described by the Indian Council for Agricultural Research (ICAR) as distinct breed types. The name Nili means blue and refers to the blue water of the River Sutlej. Ravi gets its name from the River Ravi. Nili and Ravi are no longer considered as distinct breeds, however, in both India and Pakistan. The Nili-Ravi breed is found in the pre-independence central Punjab beween 29.5° and 32.5°N latitude and 71° and 75°E longitude.

The skin and hair of Nili-Ravi are usually black although brown is not uncommon. 'Wall' eyes and white markings on forehead, face, muzzle, legs and tail switch are common in the Nili. Pink markings on udder and brisket are sometimes found in the Ravi but more rarely in the Nili. The horns are short, broad at the base and closely curled back behind the base. The body is massive and barrel-shaped with a deep frame. The head is long, bulging at the top and is depressed between the eyes. The muzzle is fine but with wide nostrils. The double chin is conspicuous.

The Nili has a more convex profile with more coarse hair on the head and face, and a conspicuous double chin. The horns are fine and tightly coiled and circular in cross-section. In the Ravi, the horns are oval in cross-section; transverse rings or pits are more conspicuous. The legs are short and bony. The rump is broad, long and slightly sloping. Pin-bones are prominent and set well apart. The tail is long, touching the ground. The udder is well developed extending far forward and backward. The milk-veins are prominent, long and tortuous. The average adult Nili female buffalo weighs about 450 kg and the male nearly 600 kg.

Pandharpuri.

Pandharpuri is an important buffalo breed in southeast Maharashtra State, India. It is a medium-sized animal having a long narrow face, a very prominent and straight nasal bone, comparatively narrow frontal bone and a long compact body. A typical characteristic of this breed is its horns which are very long, curved backward, upward and usually twisted outwards. The neck is comparatively long and thin. The udder of lactating females is medium sized, compact and somewhat hidden in between the hindquarters. The tail is long, just reaching below the hock. The switch of the tail is usually white, while hooves are black. The body colour varies from light black to deep black. In general the animals are mild in temperament.

Surti

The home tract of this breed is Kaira district and the adjoining territory of Baroda in Gujarat State, India. The skin is black or reddish and the hair silver-grey to rusty-brown. Below the knees and hocks, the hair colour is generally whitish grey. The tuft of the tail is sometimes white. Animals with white markings on forehead, legs and tail-tip are preferred. The horns are flat, of medium length, sickle-shaped and are directed downward and backward and then turn upward at the tip to form a hook. Animals are of medium size, having a straight back. The head is elongated, fairly broad and rounded between the horns. The face and muzzle are clean and sharply narrowed below the eyes, with big nostrils and muzzle. The eyes are round and bulging. The ears are medium sized with reddish colour inside. The neck is long and thin in females; thick and massive in males. The legs are of medium size with black hoofs. The barrel is well-built, of wedge shape and medium size. The rump is broad and slightly sloping. The pin bones are wide apart. The hocks are prominent and strong. The tail is fairly long, thin and flexible. The udder is well developed. The teats are of medium size and squarely placed. Mature females and males weigh around 408 and 499 kg, respectively. The milk produced by this breed is known to have slightly higher fat percentage (7.9%) than that of most river breeds.

Toda

The Toda breed of buffaloes is named after an ancient tribe (Toda) of southern India. They are quite distinct from other breeds and are indigenous to the Nilgiri hills. They have a long body, deep and broad chest, and short, strong legs. The head is heavy with horns set wide apart, curving inward, outward and forward. Thick hair coat is found all over the body. The animals are gregarious in nature. Toda buffaloes are good milkers, yielding 4.48.8 litres per day of very rich milk.

Other Indian Breeds

Apart from the above-mentioned breeds the South Kanara in the Mangalore region on the west coast of India; Sikamese in Sikkim; Assamese in Assam State; Tarai in Uttar Pradesh State, India and the southern part of Nepal; and the Manda, Kalahandi, and Sambalpuri in Orissa State, India are also found. These breeds are generally poor producers of milk but highly adapted to the ecology of their area.

Egyptian

Egyptian buffaloes are blackish grey. The horns vary from lyre to sword shape. The head is long and narrow with long and drooping ears. The chest is deep but not very wide. The hocks are wide apart, prominent and higher than the pins. The rump is sloping and the tail setting is low. Body weight varies from 360 to 800 kg (Sidky, 1951) and is usually 500600 kg. The average milk yield in organized farms is 13002000 kg with a mean around 1700 kg (El-Itriby, 1969).

European

Italian

The major concentrations of Italian buffaloes are in the region of Campania, particularly in Caserta and Salerno Provinces. Apart from these areas, Italian buffaloes are found in the Provinces of Frosinone and Latina in the region of Lazio and the Province of Foggia in the region of Puglia. The animals are short-limbed and broad in proportion to their length. They are suitable for both meat and milk production. The average milk yield ranges from 1400 to 3000 kg. The adult body weight varies from 450 to 600 kg.

Other European Breeds

Buffaloes are found in Albania, Greece, Turkey, Yugoslavia, Bulgaria, Romania and Hungary besides Italy. They are all of the same general type as Italian buffaloes and differ mainly in size.

Iranian

Buffaloes found in southern Iran are of a uniform typedark grey in colour, weighing about 400 kg and measuring 140 cm in height (Rastagir, 1950). The females produce up to 2500 litres of milk in 300 days. Males are generally used for draught and meat. The author's observations, however, differ with respect to constancy of type and colour. The buffaloes generally show great diversity in adult size, weight and colour. Most animals show white patches on head and hocks.

Iraqi.

Iraqi buffaloes are widely distributed, with foci of concentration in Baghdad, Basra, Amara, Diwaniiya, Hilla and other towns, where they are used for milk production. The largest concentration is still found in the Amara area of Shatul Arab. There is great diversity in colour, which varies from slate black to almost white. White patches on the head, legs and tail are common. The horns are generally sickle shaped. The face is slightly dished. The withers are high, and the croup and haunch bones prominent. The body is generally elongated. The udder is big in good specimens, is carried well back and has goodsized and well-placed teats. Average measurements are: height at withers, 143 cm; length from point of shoulder to pin bone, 153 cm; girth, 209 cm (Williamson, 1949; Bhat, 1975). Milk yield varies from 1600 to 2500 litres in a lactation period of 200300 days.

Swamp Buffalo

Cockrill (1967) preferred to group all the swamp buffalo types together as one breed, as no distinct breed has so far been evolved. Like the river-type nondescript buffaloes there are also many variants to be found in swamp buffaloes. The large swamp buffalo of Thailand may weigh well over 900 kg while the carabao of the Philippines or the small water buffalo of Borneo may weigh only 370 kg or even less.

Swamp buffalo are distributed from the State of Assam in India to the Yangtze Valley in China. The major concentrations are in Southeast China, Myanmar, Malaysia, Laos, Cambodia, Thailand, Indonesia, the Philippines and Vietnam. The skin is grey to slate blue, generally dark grey; white animals occur frequently. Black spots may be present on the skin of white animals and their eyes are not pink. These animals are not true albinos. They generally possess sweptback horns and are similar in general appearance, except for size, throughout the regions. The horns grow laterally and horizontally in young animals and curve round in a semicircle as the animal gets older. They are massively built, heavy bodied and stockily built; the body is short and the belly large. The forehead is flat, orbits are prominent with a short face and wide muzzle. They weigh 300500 kg when fully grown. Attempts to classify the swamp buffalo into breeds have not been very rewarding because of large diversity in conformation and colour. However, there are some types that are recognized as being distinct. The differences are mostly in horn size, body size and colour. Local strains have been described in Thailand and Laos. White animals occur with a frequency of 1% in the Philippines and 5% in Malaysia. The swamp buffalo is primarily used as a work animal in paddy cultivation. It is also used for pulling carts and for hauling timber in jungles. Milk yield of swamp buffaloes is very low (150200 kg) in a lactation period of 150200 days.

Latin America

Brazil is emerging as the major buffalo-owning nation in Latin America with the largest concentration (1.6 million) of buffaloes. There are nine other countries with sizeable buffalo populations. Most of the animals are progeny of the stock imported from Indochina in 1890; or of Murrah, Jaffarabadi, Nagpuri, Surti, and Nili-Ravi from the Indian sub-continent during the period 19071962; and of buffaloes from Italy. Most are used for milk and meat, though carabao are used for work and meat. These breeds have undergone a period of mixing but emerging breeds are:

(1) The *Brazil Murrah* derived from imports of Murrah buffalo from India.

(2) The *Jaffarabadi*, a purebred derived from the Jaffarabadi stock of India.

(3) The *Mediterrano* derived from imported Italian buffaloes and Murrah, and currently bred as purebreds.

These three breeds are being developed for milk and meat production.

Swamp buffaloes imported from Indochina are now raised as a distinct breed and have been named 'Latin carabao'.

In addition, imports of Nagpuri, Surti and Nili-Ravi have been made; all used as purebreds or as crossbreds. In addition there are crosses of breeds imported from the Indian sub-continent and from Italy, used for meat and milk production. Table 8.2 provides information on the distribution of various breeds, their utilities and countries of origin.

Genetics

Blood Groups

Work on blood groups in buffaloes was initiated by Singh (1942) at the Indian Veterinary Research Institute (IVRI) in India. He demonstrated four blood groups employing naturally occurring antibodies. The first among these was tentatively designated as J-factor. Chet Ram *et al*. (1964) showed that this factor had overlapping specification with the J-factor of cattle. It was present in red cells and serum, serum alone or was completely absent. Its inheritance was controlled by three alleles. These are one of a pair of alternate inherited characters.

The blood group factors are inherited as dominant factors. The inheritance pattern led to the recognition of seven blood group systems

Table 8.2 Distribution of various breeds of buffaloes in Latin America, their utilities and countries of origin. (*Source*: Bhat, 1997.)

Country	Breeds	Date of introduction	Type of management and production	Country of introduction and breed
Argentina	Brazilian Mediterraneo	1910	Milk production	Brazil, India, Italy, Romania
	Murrah	1980		
	Jaffarabadi	1983		
Brazil	Murrah	1890/95	Extensive for meat with some feedlot units. For dairy production intensive management is practised.	Carabao via French Guiana from Indonesia; Murrah, Jaffarabadi from India; and buffaloes from Italy (1920)
	Jaffarabadi	1907		
	Mediterraneo	1962		
	Carabao			
Colombia		1967	Meat, milk and work	Trinidad
Cuba		1983	Meat/milk	Trinidad
		1986		
Ecuador		1986		
Paraguay	Mediterraneo crossbreds Murrah	1974	Stallfed for milk	Brazil
Peru	Mediterraneo crossbreds	1966	Dairy/meat	Brazil
Surinam		1890/95	Work and meat	French Guiana, India
Trinidad	Murrah	1900	Work, meat	India
	Jaffarabadi	1924		
	Nagpuri	1938		
	Surti	1949		
	Bhadawari			
	Nili-Ravi			
	Mixture of these			
Venezuela	Mediterraneo	1920 1940/67/72	Milk and meat Extensive, stall feeding for milk/cheese	Bulgaria, India, Italy, Trinidad

involving 14 factors. The remaining eight factors were tentatively treated as independent systems. The results obtained by Khanna *et al*. (1968) on blood groups are summarized in Table 8.3.

Amano (1978) found six blood antigenic factors in swamp buffaloes in Indonesia. These are: Wh1, Wh2, Wh3, Wh4, Whs and WbJ at frequencies of 1.5, 13.0, 23.2, 21.7, 0.0 and 15.9% respectively. He also detected some of these blood groups in crossbred (swamp × river) buffaloes, but none were detected in the river or Indian buffaloes. This evidence suggests that swamp and river buffaloes are immunogenetically different.

Biochemical Polymorphism

Different forms of a biochemical compound can occur in the same species at any one time or at different times in the life of an animal. Some

Table 8.3 Blood group systems and factors. (*Source*: Khanna *et al*., 1968.)

Blood group system	Antigenic factor	No. of alleles recognized
A	AC	5
B	BDY	8
F	FG	4
N	NV	3
O	OW	4
Q	OX	4
J	J	3
L, P, R, S, T, Z, A' and B'	L, P, R, S, T, Z, A' and B'	2 each

examples of this biochemical polymorphism are listed below.

• *Haemoglobin*. Khanna & Braend (1968) recorded two rare phenotypic haemoglobin component variants. One variant exhibited three bands.

• *Transferrin*. Three transferrin phenotypes controlled by two co-dominant alleles were reported in buffaloes by Khanna (1969), Naik *et al*. (1969) and Basavaiah (1970). Khanna (1973) reported four transferrin types, namely TfDD, TfKK, TfDN and TfKN, controlled by the three co-dominant alleles, TfD, TfK and TfN, in order of decreasing anodic mobilities. Each allele controlled expression of three bands at 7.6 pH. TfK was the most frequent allele (gene frequency ranged from 0. 74 to 0.95). TfD and TfN were present in low frequencies. TfN was confined to Nili and Surti breeds.

• *Albumin*. Khanna & Braend (1968) and Juneja & Choudhary (1971) reported three phenotypes controlled by two co-dominant alleles AlbF and AlbS. The frequency of AlbF was lower (0.05 to 0.29) than that of AlbS.

• *Amylase*. Khanna (1973) described the existence of amylase isozymes, namely AmC, AmA and AmB, in order of decreasing anodic mobility.

• *Carbonic anhydrase*. Khanna & Tandon (1978) described CaC, CaF and CaS isozymes in the order of decreasing mobility in the Murrah breed. The gene frequency of CaF was highest followed by that of CaS and CaC.

• *Ceruloplasmin*. This protein is monomorphic or develops with slight change of form (Khanna, 1973).

Cytogenetics

Cytogenetic reports on buffaloes are very few. Dutt & Bhattacharya (1952) were the first to report the diploid number of chromosomes as 48 from squash preparations. Fischer (1974) reported the diploid number to be 50, using cell-culture technique. Subsequent studies (Chakrabarty, 1977; Gupta & Raychaudhuri, 1978) confirmed the findings of Fischer (1974). Chakrabarty (1977) established that there were 24 pairs of autosomes comprising five pairs of submetacentric and 19 pairs of acrocentric chromosomes. X chromosome was the longest acrocentric chromosome. Y was acrocentric but not morphologically distinct from the small pairs of autosomes.

Prakash & Balakrishnan (1993) traced the inheritance of Nuclear Organizer Regions (NORs) for chromosome pairs 3, 4 and 6. The patterns of NORs expected from different types of parental matings agreed with the observed patterns in the progeny. The authors concluded that NORs followed Mendelian inheritance and suggested that these heritable chromosome loci could be used as genetic markers in selection.

Fischer (1974) reported 48 chromosomes (5 metacentric and 18 acrocentric pairs and X and

Y) in swamp buffalo. The Murrah buffalo has one additional acrocentric pair of chromosomes, making the diploid number 50. Investigations on swamp × Murrah buffaloes with 50, 75, 87.5 and 93.75% swamp buffalo blood, respectively, revealed that the diploid chromosome number of the first two groups was 49, whereas the second two groups had the same karyotype as that of purebred swamp buffaloes. All the hybrids showed normal fertility.

Chavananikul (1994) investigated the karyotype of 50% Murrah50% swamp, 25% Murrah75% swamp, 75% Murrah25% swamp and 87.5% Murrah12.5% swamp, and reported that 50% Murrah crosses possessed 49 chromosomes, while 25% Murrah crosses had both karyotypes having 48 and 49 in the ratio of 1:1. The 75% and 87.5% Murrah had two types but different karyotypes of 49 and 50 chromosomes in the ratio of 1:1.

The evolutionary history of Bovidae is poorly understood (Curtain *et al*., 1973). Hence, studies on molecular markers of phylogenic significance is of value in understanding relationships between closely related species of Bovidae. In this connection, satellite DNA is of potential interest (Curtain *et al*., 1973). It is known that satellite DNAs of even closely related species differ markedly (Henning & Walker, 1970). Wherever tested, the DNA of this centrome-rich heterochromatin is largely composed of sequences of nucleotides repeated many times (Botchan, 1974). These centromeric sequences are simple and tandemly arranged and can often be separated as satellites from the bulk of the DNA by a variety of equilibrium centrifugation techniques. The apparent pivotal role of the centromere in mediating chromosomal arrangements in the Bovidae made it desirable to investigate the pattern of highly repetitive DNA sequences in the buffalo (*Bubalus bubalis*) and cattle (*Bos indicus* and *Bos taurus*).

This hypothesis of Robertsonian translocations altering complex regulation systems has been shown at molecular level, to be operative in organization and variability of cattle and buffalo satellite DNAs (Beckmann *et al*., 1986; Kumar *et al*., 1991; Rasool *et al*., 1992; Ganai *et al*., 1997b; Misra *et al*., 1997).

Restriction Fragment Length Polymorphism (RFLP)

RFLP is a promising recombinant DNA technique which allows study of genetic variation in terms of nucleotide sequences and permits quantification of variation in terms of nucleotide diversity. These variations, once established, can be correlated with different metric traits and used as selection criteria. This approach can also lead to identification of quantitative trait loci (QTL). These loci can be manipulated in breeding programmes.

Repetitive DNA Sequences

All eukaryotic genomes contain many DNA sequences that are repeated a few to millions of times, forming a class of highly repetitive DNAs called the satellite DNAs. These satellite DNAs are supposed to have a role in the determination of chromosomal architecture of cell nuclei and have some role in gene expression and regulation. Eight types of satellite DNAs have been reported in cattle (Makaya *et al*. 1978). Bhat *et al*. (1990) began a study of buffalo satellite DNAs in 1988 to generate baseline data on this species. It was considered that these studies would throw some light on the evolutionary relationship between cattle and buffaloes. Restriction endonucleases Pst I, Bam HI, Hind III, Eco RI, Bgl II, Pvu II, Msp I and Taq I were used. A homologous satellite DNA fragment (Buffalo Pst 1-0.7 kb fragment) was used to explore the organization of different satellites. The findings were suggestive of the presence of three or more satellites in the buffalo genome. There was no variation in satellite DNA among individuals as well as between sexes with reference to these enzymes, though they included both hexacutters as well as tetracutters. No site variation exists in buffalo satellite DNA with reference to these enzymes (Kumar *et al*., 1991).

Buffalo DNA reveals the same periodicities with Pst I restriction enzyme using homologous Pst I-0.7 kb fragments as was shown with cattle Eco RI-1.4 kb fragment. It can be concluded that buffalo Pst I-0.7 kb fragment has high sequence homology with cattle Eco RI-1.4 kb fragment. The differences in intensities of different bands suggest loss of repetitive DNA in the process of formation of metacentric chromosomes by centric fusion. Further studies in this direction will certainly help to unravel the molecular nature of the evolutionary process at the divergence level of cattle and buffalo.

A detailed investigation was taken up to compare cattle and buffaloes using restriction endonucleases *Sma*I, *Msp*I, *Taq*I, *Hae*III, *Hinff*III, *Eco*RV, *Sac*I, *Alu*I, *Kpn*I and *Eco*RI (Ganai *et al*., 1997b,c,d). Five repetitive DNA bands of 2.9, 2.4, 1.2, 1.0 and 0.4 kb were observed in buffalo DNA digests, with *Sma*I. Out of the five bands, three bands (0.4, 1.2 and 2.4 kb) were multiples of 0.4 kb fragment, whereas bands of 1.0 and 2.9 kb size may either be part of some other satellite or of the same satellite with changed periodicity, probably due to a recombination event specifically, unequal crossovers. These crossovers could lead to rapid changes in the number of repeats in the array. This is supported by the fact that a new repetitive DNA fragment of 2.9 kb has been generated in buffalo. The formation of a new satellite sequence, in buffalo, may be a post-divergence event with changed architecture of some chromosomes. This is inferred from the fact that centromere of mammals are associated with repetitive DNA sequences. The 0.4, 1.0 and 1.2 kb bands were common to cattle, but 2.4 and 2.9 kb bands of buffalo, and 2.8, 3.2 and 3.6 kb bands of cattle were species specific. The 1.2 kb band was prominent in both the species, a result of selective amplification of tandem array due to its specific location in chromosome(s). The overall low intensity of repetitive DNA bands in buffalo as compared to those in cattle was indicative of loss of DNA of satellite(s) due to Robertsonian translocation. The repetetive DNA bands in buffaloes using various endonucleases are shown in Table 8.4.

Unique DNA Sequences.

The genetic variability in unique DNA sequences (structural genes) can be studied with

Table 8.4 Molecular weights of the repetitive DNA bands (kb) of buffalo after restriction enzyme digestion followed by electrophoresis through 1% agarose gel and ethidium bromide staining. (*Source*: Ganai *et al*., 1997d.)

Sma I	Mso I	Sac I	Alu I	Taq I	Hae III	Hinf I	Eco RV	Eco RI	Kpn I
		5.58		1.48	1.10	1.46			
		4.30*	0.98	1.26		1.26	3.0		
2.9	0.65					0.89	2.0		
			0.56	0.95		0.56			3.5
2.4	0.45		0.49			0.47			
1.2	0.30					0.38		2.30	3.1
1.0	0.25			0.42		0.28			
0.4						0.26		1.58	
				0.28		0.24		1.47	
	0.12					0.20			
	0.10					0.18			
	0.08							1.00	
								0.90	

Note: *Doublet.

the help of molecular biology techniques. Four genesthe thyroglobulin gene (a sequence supposed to be more conserved), the major histocompatibility complex (a less conserved gene complex having both conserved and highly variable sequences), growth hormone, and whey protein geneswere studied in buffaloes.

Thyroglobulin Locus (Tg Locus)

Thyroglobulin is a large dimeric protein which is the biosynthetic precursor of thyroid hormone. Thyroid hormone is essential for normal growth and neurological development in mammals (Mercken *et al*., 1985).

Analysis of buffalo thyroglobulin gene (Tg) showed that all the four cDNA clones (of cattle Tg gene) successfully hybridized with buffalo genomic DNA, indicating that there exists a high sequence homology between cattle and buffalo genomes. Comparison of nucleotide diversities in the two species revealed that buffaloes are 13 times more variable than cattle at this locus.

Histocompatibility Locus (MHC Locus)

The major histocompatibility locus has been associated with different diseases. The cattle MHC system known as BoLA (bovine lymphocyte antigen) locus is reported to be associated with many diseases such as mastitis (Solbu *et al*., 1982), tick infestation (Stear *et al*., 1984) and occular squamous cell carcinoma (Caldwell & Cumberland, 1978).

Growth Hormone (GH)

The exogenous bovine growth hormone (bGH) performs versatile functions in the body when injected in animals. Since the GH is galactopoietic it improves the biological efficiency of milk production without jeopardizing milk quality and processing characters. The galactopoietic action of growth hormone is homeostatic regulation of metabolism by redirecting the partitioning and use of absorbed nutrient to milk production. There is a 635% increase in milk production by exogenous supplementation of GH in lactating dairy animals. GH/rbGH orchestrates homeototic control over intermediary metabolism of glucose, fat and protein in combination with its direct and indirect effects on mammary secretory tissues. This encourages increased synthesis and secretion of milk by the mammary gland.

Restriction Fragment Length Polymorphism (RFLP) with TaqI

In buffaloes only two restriction fragments were observed with the size of 4.5 and 3.6 kb with Taq I. The frequencies of these two fragments were 58.3 and 41.7% respectively (Table 8.5; Fig. 8.1).

It can now be conclusively stated that the polymorphism exists in restriction fragments associated with GH locus. The presence of 4.5 kb fragment in both the species is the main site of the GH locus. Use of markers to assist in selection of animals for quantitative traits requires segregating alleles at reasonable frequencies in animals with superior breeding values for production characteristics. The frequency of poly-

Table 8.5 Allelic frequencies of restriction fragment lengths associated with growth hormone gene in Murrah buffaloes. (*Source*: Ganai *et al*., 1997a.)

Sample no.	Enzyme	*n*	Restriction fragment size (kb)	Frequency (%)
1	Eco RI	22	4.5	95.5
			12.6	4.5
2	Taq I	24	4.5	58.3
			3.6	41.7

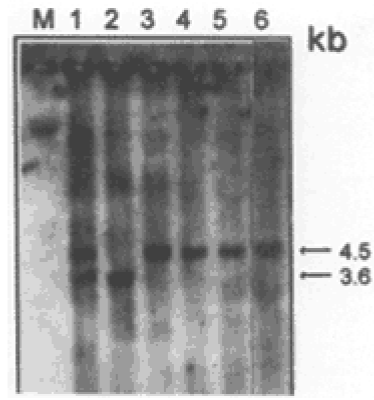

Fig. 8.1
Southern blots of buffalo genomic DNA digested with Taq I enzyme and hybridized with ovine growth hormone cDNA probe.

morphism detected in this study (Ganai *et al*., 1997a), indicates that genetic variation does exist, and could be utilized for this purpose.

Whey Protein Gene Polymorphism

The quality of milk is largely dependent on milk proteins. These proteins exhibit a very high degree of polymorphism in cattle, and correlations have been described between allelic variants of these fragments with milk protein genes, milk yield, and quality of milk proteins. All major milk proteins have genetic variants transmitted through simple Mendelian inheritance without dominance. Of the six major milk proteins two whey proteins, namely a-lactoglobulin (a-la) and b-lactoglobulin (b-lg) have also considerable influence on the quality and quantity of milk production.

b-Lactoglobulin Locus

To date no biological function for b-lg has been discovered. The amino acid composition is such that the protein is of high nutritional value, but the molecular properties, particularly the acid stability, lead to the supposition that some other more specific function for this protein exists.

Eight variants of the b-lg have so far been reported in cattle. Buffalo b-lg appears to be similar to that of cattle but differs with regard to sequence. The possibility of using milk-protein genetic variant as biochemical markers to predict future performance of the animal has resulted in much work on their influence on various production variables. The effect of genetic variants on manufacturing properties of the milk are more consistent than those on milk yield and gross composition.

Amplification of a-La Gene Fragments

Research indicates that buffalo a-la shows more sequence homology with a-la B allele of cattle than with the a-la A allele and probably it is the variant of the a-la B allele which has descended from the common ancestor in antiquity.

Polymorphism of Mitochondrial DNA (mt DNA)

Mitochondrial DNA (mt DNA) is maternally inherited and changes in the nucleotide sequence occur faster with a substitution rate of 510 times higher than in nuclear DNA (Hutchison *et al*., 1974; Upholt & David, 1977; Brown, 1980; Watanabe *et al*., 1985). The size of the buffalo mt DNA is 16.4 kb (approx.) as reported by Misra *et al*. (1997).

Bhat *et al*. (1990), Amano *et al*. (1994) and Misra *et al*. (1997) reported the polymorphism of mt DNA in buffalo. The number of cleavage sites for 15 restriction endonucleases and the molecular length of fragments are provided in Table 8.6. There was no site variation with respect to the 14 enzymes described except in Bgl I (Fig. 8.2).

The published reports indicate that mt DNAs have highly conserved restriction sites but for Bg II, the only restriction enzyme which can differentiate buffaloes in two groups A and B with two and three sites (Table 8.6) with preponderance of A type (90%) in this population. D-loop in mt DNA has approximately 1.1 kb length (Misra *et al*., 1997) with hypervariability in initial 556 bp. The remaining portion of D-loop is comparatively stable. Hence, this portion of D-loop, like in other species, can be used to classify the buffaloes on basis of maternal lineages. There was

Table 8.6 Number of cleavage sites of buffalo mt DNA for 13 restriction endonucleases and the molecular lengths of fragments. (*Source*: Bhat *et al*., 1990.)

Restriction endonuclease	No. of cleavage sites	Molecular lengths of fragments (kb)
Ava I	3	10.96, 3.47, 1.32
Ava II	3	11.22, 3.8, 1.3
A	2	9.7, 6.6
B	3	8.6, 6.6, 1.1
Bgl II	3	11.2, 4.22, 0.8
Dra I	7	6.2, 3.7, 1.9, 1.9, 1.45, 0.55, 0.55
EcoRI	4	4.67, 4.30, 3.99, 1.95
Hind III	3	8.71, 5.01, 2.66
Hpa I	3	9.4, 5.13, 1.67
Kpn I	0	
Pst I	1	16.4
Sal I	0	
Xho I	2	13.1, 3.3
BamHI	4	8.4, 3.9, 3.6, 0.5

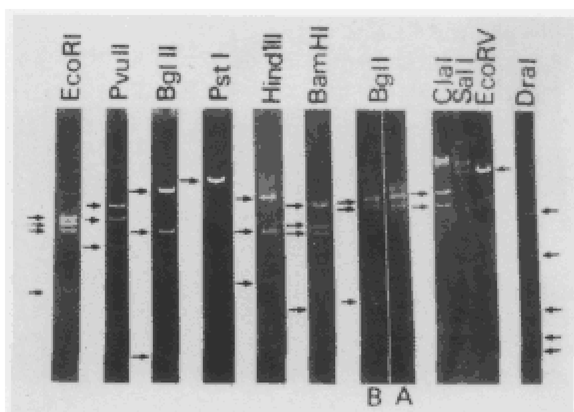

Fig. 8.2
Ethidium bromide stained agarose (0.7%) showing 11 restriction endonuclease cleavage patterns of buffalo mtDNA. Bg II generated two types of mtDNA (A type, two sites; B type, three sites).

minor homology between cattle and buffaloes at mt DNA level as scarcely any of the restriction fragments of buffalo mt DNA matched those of cattle mt DNA.

Adaptability.

The fact that buffaloes are found in widely differing geographical conditions suggests that this species is adaptable to a wide range of environmental conditions. This is particularly true of the river buffalo. While the buffalo is remarkably versatile, it has less physiological adaptation to extremes of heat and cold than cattle. Body temperatures of buffaloes are actually lower than those of cattle, but buffalo skin is usually black and heat absorbent and only sparsely protected by hair. Buffalo skin has one-sixth the density of sweat glands that cattle skin has, hence buffaloes dissipate heat poorly by sweating. If worked or driven excessively in the hot sun, a buffalo's body temperature, pulse rate, respiration rate, and general discomfort increase more quickly than those of cattle. Buffaloes prefer to cool off in a wallow rather than seek shade. They may wallow for up to 5 hours a day when temperature and humidity are high (Fig. 8.3).

In shade or in a wallow buffaloes cool off quickly, perhaps because a black skin, rich in blood vessels conducts and radiates heat efficiently. Nonetheless, wallowing is not essential. Experience in Australia, Malaysia, Trinidad and elsewhere has shown that buffaloes grow normally without wallowing as long as adequate shade is available.

High humidity affects buffaloes less than cattle. In fact, if shade or wallows are available, the

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Fig. 8.3
Buffaloes wallowing in a river in India.

acclimatization of buffaloes may be superior to cattle in humid areas. In southern Brazil, trials comparing buffaloes and cattle on subtropical riverine plains have favoured the buffalo.

The buffalo is considered essentially an animal of the plains, but the native buffaloes of Nepal are found distributed from the plains of the Terai region up to an elevation of 2700 m. Buffaloes of the Murrah breed from the plains of India have been introduced into the mid-altitude region of Nepal. These animals have easily adapted to this hilly environment and are thriving. In Bulgaria buffaloes are used for drawing snow-ploughs. A herd of swamp buffaloes is thriving at Kandep in Papua New Guinea, 2500 m above sea level.

The best milk breeds of buffaloes in India and Pakistan are mostly confined to areas where the summer temperature rises above 46°C and the winter temperature falls below 4°C. Nondescript buffaloes are scattered all over India and Pakistan. The buffalo is capable of maintaining itself in good condition where there is barely enough sustenance to maintain life, such as stubble fields or marshy lands with sedge, reeds, water weeds and grasses. It can also work and supply milk when fed the poorest of diets.

The swamp buffalo is not as adaptable as the river buffalo. They are usually found only in swampy and marshy areas, and in hot climates. Swamp buffaloes must have almost unlimited access to water in order to keep cool.

Water buffaloes are well adapted to swamps and to areas subject to flooding. They are at home in the marshes of southern Iraq and of the Amazon, the tidal plains near Darwin, Australia, the Pontine Marshes in south-central Italy, the Orinoco Basin of Venezuela, and other areas. In the Amazon, buffaloes (Mediterraneo and swamp breeds) are demonstrating their exceptional adaptability to floodable areas. Buffalo productivity outstrips that of cattle, with males reaching 400 kg in 30 months on a diet of native grasses.

When exposed to direct solar radiation or if made to work in the sun during hot weather, buffaloes exhibit signs of great distress. On account of their dark skin and the sparse coat of hair on the body, there is great absorption of heat from direct solar radiation. There is also less efficient evaporative cooling from the body surface of the buffalo due to a rather poor sweating ability. If kept in shade and rested or put to work at a slow pace unexposed to the sun during the hot weather, their tolerance to heat is of no mean order. Their thermoregulatory mechanisms function efficiently and are more effective in the shade than are those of cattle, when the speed of recovery from the effect of stress is taken as a measure of efficiency (Badreldin & Ghany, 1952; Mullick, 1960). Results of investigations by Pandey & Roy (1969) on seasonal changes in body temperature, cardiorespiratory, haematological attributes, body water and electrolytic status of the buffalo under conventional farm mangement lend further support to this view. Pandey & Roy (1969) emphasized that the plethora of changes observed in the buffalo are orderly manifestations of various physiological adjustments necessary for adaptation to higher environmental temperature and that these changes are within normal physiological limits.

Under cool, comfortable conditions the average rectal temperature, pulse rate and respiration rate of the buffalo are lower than those of the Zebu, but exceeds them on exposure to hothumid conditions. Buffaloes become more hyperthemic on exposure to direct sun due to a black skin and scant hair on the body. Body temperature rises sharply within the range 0.3°C to 2.4°C depending on the environmental temperature and duration of exposure (Badreldin & Ghany, 1952; Mullick, 1960). Temperature falls sharply to normal, however, on shifting the exposed animals to sheds, splashing them with cold water or allowing them to wallow. The effect of stress on exposure to a hot-arid environment is more severe in buffalo heifers than in zebu heifers.

The rise in climatic temperature reduces heat dissipation by convection and radiation due to the drop in the temperature gradient (skin temperatureair temperature). The first response of the animal is to elevate skin temperature by vasodilation of the skin to bring more heat from the core by fast circulating blood to the skin. This mechanism is more effective in buffaloes than in cattle due to the absence of an intervening hair coat in buffaloes. However, this mechanism is not effective with a high rise in air temperature. With failure of heat dissipation by physical (nonevaporative) channels, the animal increases water vaporization from its surfaces, skin and respiratory tract. Since buffaloes have apocrine sweat glands they rely less on active sweating for skin vaporization, and depend more on respiratory vaporization by breathing faster.

Very few reports are available about the heritability of environmental adaptation phenomena, more particularly of thermo-cardio-respiratory responses in buffaloes. Sethi & Nagarcenkar (1981) studied the inheritance of heat tolerance in buffaloes by measuring change in the body temperature and pulse rate before and after exposure to direct solar radiation for 6 hours. They reported heritability estimates of 0.24 ± 0.19, -0.05 ± 0.12, 0.39 ± 0.24 for initial body temperature, initial pulse rate and heat tolerance index (Iberia heat tolerance test).

Though the thermoregulatory mechanism of the buffalo is reasonably efficient there are reports of the reproductive system being adversely affected by climatic changes. The quality of the buffalo semen deteriorates like that of cattle, sheep and goat semen during summer, but unlike other species the Murrah buffalo also fails to retain the quality of its semen at a high level during winter (Mukherjee & Bhattacharya, 1953; Kushwaha *et al*., 1955; Sengupta *et al*., 1963).

The buffalo is sensitive to extremes of climate and has lesser ability than cattle to adapt itself to a colder climate. Failure during the winter to produce semen of high quality as is produced in spring may be the result of the sensitivity of the buffalo to a cold environment.

Although generally associated with the humid tropics, buffaloes have been reared for centuries in temperate countries such as Italy, Greece, Yugoslavia, Bulgaria, Hungary, Romania, and Azerbaijan. Buffaloes are also maintained on the high, snowy plateaus of Turkey as well as in Afghanistan and the northern mountains of Pakistan.

The buffalo has greater tolerance to cold weather than is commonly supposed. The current range of the buffalo extends as far north as 45°N latitude in Romania, and the sizeable herds in Italy and the former Soviet Union range further than 40°N latitude. Cold winds and rapid falls in temperatures cause illness, pneumonia and sometimes death. Most of the animals in Europe are of the Mediterranean breed, but other river-type buffaloes (mainly Murrahs from India) have been introduced to Bulgaria and countries formerly in the Soviet Union which indicates that river breeds at least have some cold tolerance.

Since buffaloes have sparse hairs they have no way to engage an efficient insulative coat to check heat loss from their body. Even neonatal and young calves with their denser hair cover gain less value as the pili muscles are weak in performing hair erection function to increase the thickness of the coat in accordance with the degree of coldness. The animal has to increase the metabolic rate to compensate for faster heat loss. The subcutaneous fat layer, however, is a good substitute of the outer coat for insulative heat preservation, if it is developed to effective thickness, a character waiting anatomical and physiological studies. Folk (1974) drew attention to an important fact that the subcutaneous fat has abundant blood supply, rejecting the erroneous impression of feeble circulation. He stated that this plenitude of blood permits effective deposition and utilization of fat in this depot. Vasomotion in skin is also a primary physiological response to fluctuations in environmental temperature. Since the skin of the buffaloes is very thick (0.610.0 mm) vasoconstriction plays a great part in heat conservation in cold weather.

Some degree of seasonal variation in breeding efficiency is usual with most domestic livestock, but the variation is more marked in the buffalo. A seasonal trend of reproduction among the Philippine buffaloes was first reported by Villegas (1928). Subsequently, this peculiarity of breeding of the buffalo was reported by many workers from India, Pakistan, Egypt, Bulgaria and Italy. Analysing the data from various farms in India and Pakistan, Rife (1959) observed that there was practically no incidence of oestrus during the hot months and that the oestrous symptoms were not pronounced during the adjacent periods. Bhat (1983) noted that this observation could not be supported from the data of military dairy farms. This showed that female buffaloes came in heat regularly during summer and that there was no particular season of breeding for Murrah buffaloes, although there was a tendency for better performance during the cooler months. They noted that buffaloes in the marshes of southern Iraq breed throughout the year, but more so in the spring and a little less so in the autumn.

The depression of the breeding function of buffaloes during hot months led many to suspect that it was in some way related to high environmental temperatures or to the temperaturehumidity complex of the tropical summer. Others considered that in addition there might be a photoperiodic effect. Roy *et al*. (1968) conducted a series of systematic investigations. From the results of the earlier experiments it appeared that air temperature and humidity had a direct effect on breeding efficiency as improvements in breeding performance were obtained by alterations in housing conditions to provide relief from heat stress. Subsequent investigations have suggested that the photoperiod, rather than the heat stress factor, is primarily involved. Further studies and more critical evaluation of the experimental results led this team to believe that manifestation of oestrous symptoms is poor during the summer months but that with proper husbandry practices it is possible to make the buffalo breed fairly uniformly all through the year. There are many questions relating to the reproduction of the buffalo that still remain to be investigated, and it is very likely that a number of factors singly or in combination are operational in causing the marked seasonal breeding behaviour.

Economic Parameters

Liveweight

Information on growth, reproduction and production parameters and selection studies across various breeds has accumulated since the late 1970s. The details are discussed in the following paragraphs. On the basis of body size Murrah, Nili-Ravi, Egyptian and Italian breed/breed types could be classified as large; Surti and Bhadawari as medium and Kundi as small sized breeds. Body weights at various ages provide a measure of growth and size, and reflect the suitability of a breed or strain to a particular ecosystem. Its study is important from the point of view of early maturity and general adaptability.

At Birth

The birth weight in large breeds varies from 27 to 41 kg (Nautiyal & Bhat, 1977; Basu & Rao, 1979a) and from 24 to 30 kg in medium sized breeds (Venkatachar & Sampath, 1978; Chowdhary & Barhat, 1979).

Month/season and year/period have significant effect on birth weight (Johari & Bhat, 1979; Nautiyal & Bhat, 1979). Summer-born calves are heavier than those born in autumn.

Sire has significant effect on birth weight (Basu & Rao, 1979). Most workers observed the differences between sexes to be significant, males having higher birth weight than females.

Galal & Fahmy (1969) and Fahmy (1972) reported significant effect of parity. The birth weight increased from first to sixth calving. The weight and age of the dam at calving also influences the birth weight, it being higher in females with higher age and weight at calving (Misra *et al*., 1970; Fahmy, 1972; Basu *et al*., 1978; Alim & Taher, 1979).

The heritability of birth weight in Indian buffaloes ranges from 0.16 to 0.74 (Ragab & AbdEl-Salam, 1963; Basu & Rao, 1979) However, most of the heritability estimates based on data adjusted for significant non-genetic effects are low, 0.16 ± 32 (Tomar & Desai, 1967; Sreedharan & Nagarcenkar, 1978; Basu & Rao, 1979). Nautiyal & Bhat (1979) however, reported a slightly higher estimate of 0.56 ± 0.09 (using adjusted data) for this trait.

The phenotypic correlations of birth weight with body weights up to first calving though positive were low (0.020.34) and gradually declined with increase in age (Johari & Bhat, 1979a; Nautiyal & Bhat, 1979). A similar trend was noted for genetic correlations. The phenotypic correlations of birth weight with age at first calving and first lactation yield are also low and nonsignificant (Marwaha, 1974). The low genetic and phenotypic correlations of birth weight with body weights at later ages and of birth weight with age at calving or milk yield suggest that birth weight cannot be used to predict either the mature body weight, age at calving or milk yield.

Weight for Age

Body weights at different ages across the breeds are given in Table 8.7. Among Indian breeds, the Nili-Ravi had the highest weight at 24 months followed by the Murrah, while the Surti had the lowest weight. Egyptian heifers have lower weights at 24 months than Nili-Ravi. Italian buffaloes grow at a fast rate and at 24 months of age weigh considerably more, around 450 kg. Knapp (1957) attributed this difference not to differences between breeds but to nutritional status. Reports on body weights in male calves are generally not available because males, except those to be retained for breeding, are culled at an early age.

Rathi *et al*. (1973) and Basu & Rao (1979) reported that weights at 9, 12 and 18 months were significantly influenced by the season of birth. Calves born in cooler months (October to March) had a higher rate of gain and had higher weights at 3, 6 and 12 months of age than those born in hotter months. This could also be due to availability of better-quality green feed during the cooler months.

The heritability estimates of body weights at various ages range from 0.27 ± 0.09 to 0.72 ± 0.11. Nautiyal & Bhat (1979) reported heritability estimates of 0.49 ± 0.09, 0.42 ± 0.08, 0.39 ± 0.09, respectively, for body weights at 3, 6 and 12 months (Table 8.8). These results suggest that

Table 8.7 Body weight at birth, 3, 6, 12 and 24 months in female buffaloes.

Breed	Source	Body weight (kg)					
		Birth	3 months	6 months	12 months	24 months	First calving
Egyptian	Ragab & Abd-El-Salam, 1963	36.41	106.03	120.09	220.00	340	
Murrah	Basu & Rao, 1979	31.68	70.56	112.14	185.09	283.21	446.42
Murrah Grade	Johari & Bhat, 1979a	31.14	77.79	127.10	212.59	326.05	461.91
Nili-Ravi	Sharma & Basu, 1984	30.00	86.33	144.50	243.25	395.22	531.06
Surti	Basavaiah *et al*., 1983	25.60	58.09	79.64	109.37	205.13	
Jaffarabadi		36.15				308.30	
Carabao		36.75				322.70	
Italian	Knapp, 1957	34.59	105.09	175	266	450	450
Mediterraneo		36.80				368.85	

selection would be effective in improving body weights/growth at 6 or 12 months.

The phenotypic and genetic correlations among the body weights, in general, were high and with increase in age declined gradually. The genetic correlation, in general, was higher than the phenotypic correlation (Johari & Bhat, 1979a; Nautiyal & Bhat, 1979). The correlations of body weights at later ages with weight at first calving were positive and ranged from moderate to high (Nautiyal & Bhat, 1979; Sharma & Basu, 1984) thus suggesting that higher weights at 1 and 2 years would lead to a higher weight at first calving. The genetic and phenotypic correlations of body weights at various ages with age at first calving were, however, negative (Marwaha, 1974), suggesting that an increase in weight would lower the age at first calving.

Moderate to high heritability estimates for body weights at various ages and positive correlations among them, suggest that these should be utilized in formulating the breeding plan by giving appropriate weightage to body weights in the selection criterion so that higher body weights/growth rates leading to early maturity could be achieved.

At First Heat

Basu *et al*. (1984) reported average weight at first heat in Murrah buffalo heifers as 336.6 ± 2.8 kg with coefficient of variation of 12.3%. The frequency distribution of weights at first heat showed that 41.7% of the heifers weighed between 321 and 360 kg. Positive phenotypic correlations of weight at first heat with age at first calving (0.25) and weight at first calving (0.42) were observed. The heritability estimate for the trait was 0.30 ± 0.19.

At First Calving

The weight at first calving in the Murrah varies from 449 to 525 kg (Kanaujia, 1978; Johari & Bhat, 1979a; Basu *et al*., 1984). Singh & Desai (1962) reported the adult body weight in Bhadawari buffaloes as 425 kg.

Buffaloes calving for the first time in summer (MarchJune) are heavier at first calving than monsoon (JulyOctober) and winter (NovemberFebruary) calvers. The significant differences in weight at first calving between most and least calving seasons for this trait were attributed to favourable climate and availability of sufficient green feed during pregnancy (Rathi *et al*., 1971).

Differences between farms, periods and sires for weight at first calving are significant (Johari & Bhat, 1979a). Age at first calving also significantly influences the weight at first calving (Basu *et al*., 1984). Johari & Bhat (1979a) and Reddy (1980) reported heritability estimates of 0.34 ± 0.14, 0.23 ± 0.05 and 0.19 ± 0.06, respectively, for this trait.

Table 8.8 Heritability and genetic and phenotypic correlations among various growth traits in Indian buffaloes. (*Source*: Nautiyal & Bhat, 1979.)

	Body weight at					
	Birth	26 weeks	52 weeks	24 months	36 months	First calving
Birth	0.56 ± 0.09	0.11 ± 0.02**	0.10 ± 0.02**	0.06 ± 0.02	0.14 ± 0.03*	0.08 ± 0.03**
26 weeks	0.18 ± 0.12	0.42 ± 0.08	0.62 ± 0.02**	0.40 ± 0.02**	0.33 ± 0.03**	0.22 ± 0.03**
52 weeks	0.26 ± 0.13*	0.89 ± 0.31**	0.39 ± 0.09	0.57 ± 0.02**	0.46 ± 0.04**	0.21 ± 0.03**
24 months	0.10 ± 0.13	0.65 ± 0.07**	0.68 ± 0.08**	0.40 ± 0.08	0.60 ± 0.03**	0.19 ± 0.03**
36 months	0.43 ± 0.16*	0.32 ± 0.19	0.67 ± 0.13**	0.49 ± 0.16**	0.20 ± 0.09	0.40 ± 0.03**
First calving	0.19 ± 0.17	0.31 ± 0.19	0.34 ± 0.19	0.50 ± 0.15**	0.64 ± 0.12**	0.15 ± 0.16

*$P < 0.05$, **$P < 0.01$. Above the diagonal are phenotypic, below the diagonal are genetic correlations; along the diagonal are heritability estimates.

The phenotypic correlations between weight and age at first calving ranges from 0.15 to 0.39 (Marwaha, 1974; Reddy, 1980). The genetic correlations are positive and high (0.68 to 0.74), suggesting that selection for either trait would lead to correlated positive change in the other.

The phenotypic correlations between weight at first calving and first lactation yield is 0.15 ± 0.45 (Marwaha, 1974). The genetic correlation between weight at first calving and first lactation milk yield (300 days) is 0.74 ± 0.09. The high genetic correlation suggests that animals with higher weight at calving would have higher first lactation yield.

Growth Rate

Growth rate, in general, is linear from birth to 36 months (Amble *et al*., 1970; Rathi *et al*., 1973; Nautiyal & Bhat, 1977). Nautiyal & Bhat (1977) reported average daily gains of 0.497, 0.547 and 0.503 kg for 03, 36, 612 months age-interval, respectively. The average daily gains thereafter, up to 36 months, for different periods varies between 0.328 and 0.377 kg. The overall average daily gain from 0 to 36 months is 0.406 g.

Sharma & Basu (1984) reported the mean daily body weight gains for different age-intervals as 647 g (birth to 12 weeks), 657 g (12 to 24 weeks), 552 g (24 to 36 weeks), 512 g (36 weeks to 1 year), 416 g (1 to 2 years) and 271 g (2 years to age at first calving) in Nili-Ravi buffaloes. The daily gain in body weight increases from birth to 24 weeks, being maximum during 12 weeks to 24 weeks, but declines thereafter up to age at first calving.

The birth weight of the Egyptian buffalo is slightly higher than that of the Italian buffalo and the rate of growth in the two types is very similar up to the age of 3 months. After this period, the Italian buffalo grows at a much faster rate and at 2 years of age weighs considerably more than the Egyptian buffalo. Knapp (1957) attributed the difference in growth rate in favour of the Italian buffalo not to differences between the breeds, but primarily to the difference in nutritional status. Average daily gains are, respectively, 0.728 kg and 1.163 kg in the Egyptian and Italian buffaloes.

In Caucasian buffaloes daily gain is of 0.81.2 kg on intensive fattening (Agabeili *et al*., 1971).

Heat stress during summer depresses the growth rate of young buffalo calves by about 15% (Tripathi *et al*., 1972). In Iraq average daily gains of 0.728 kg and 1.163 kg have been reported in two feedlot trials (Bhat, 1975).

The above results suggest that the period up to 1 year of age could be economically utilized in feedlot for maximizing growth rate. It seems that present potential of the species is around 500 g per day up to 1 year on normal diet, and this can be improved further through selection of fast-growing males.

Reproduction

Male and Female.

Male

Spermatogenesis in the buffalo starts quite early in life and meiotic division of the spermatogonial cells has been observed as early as at 1 year of age in the Indian buffalo (Dutt & Bhattacharya, 1952). It is likely that spermatogenesis may start even earlier. There is a belief that the buffalo grows at a slower rate than cattle, even with good feeding and management, and attains sexual maturity at a later age. There are, however, reports from Italy and Russia of buffalo bulls being put to service at around 2 years of age and this is not much different from the age at which male cattle are used for breeding. The age at first service of the buffalo bull is around 3 years in Iraq although some well-fed and well-developed bulls may be put to stud at 2 years. In India, Pakistan and Egypt the buffalo bull is generally not used at stud before 3 to 3.5 years of age. The duration over which the buffalo bull may be retained for service is as yet a subject of individual opinion as no systematic study appears to have been made on this aspect of husbandry. MacGregor (1941) stated that in the buffalo 'by 6

or 7 years there is frequently a loss in potency with a rising proportion of unsuccessful services but desire continues until he is 12 years or more, during which time his muscular strength seems to increase. Complete senility, i.e. loss of muscular strength as well as desire, does not manifest itself until he is over 15 years of age'. Others have expressed the view that the buffalo bull can be retained for service up to 1015 years of age. Buffalo bulls are used for breeding in Iraq up to 10 years of age. In Italy, bulls are replaced after only 4 or 5 years of service.

Divergent views have been expressed about the number of female buffaloes to be allowed per bull. According to MacGregor (1941) 'a good buffalo bull of the river type can serve 100 cows a year, but it is unusual to allow more than 12 cows to each bull as each of them will be served several times during her heat'. Hafez (1952) stated that a buffalo bull can serve 50 females in a year. Lazarus (1946) opined that the buffalo bull should be used sparingly so that he does not serve more than 75 times a year. The number of females allotted to one buffalo bull in Iraqi villages varies widely from 12:1 to 600:1, but in the majority of villages it is less than 100:1.

In Egypt, 75% of the services in buffaloes occur during the 4 months of the year that constitute the breeding season. A bull is used at least three times a week during this period. With such heavy service there is deterioration in semen quality and consequent lowering of fertility (Asker & El-Itriby, 1958). In Egypt, with three semen collections per week from the buffalo bull there was a comparative deterioration in the semen quality. With semen collection twice a week for a period extending over 3 years, there was no deterioration in semen quality or sex vigour in Murrah buffalo bulls. Sex vigour of the buffalo bulls declines during the hot summer in the north Indian sub-continent and improves with the onset of the cold season. With the introduction of artificial insemination (AI) and wider use of frozen semen technique, this aspect has lost much of its significance in most countries where milk production is in high focus and husbandry has improved.

Female

The age at puberty of buffalo heifers shows a wide variation, but is generally much later than cattle. Basu *et al*. (1984) reported the age at first heat was 30.6 months in Murrah buffaloes. Nagpuri buffaloes come in heat late, at 4248 months of age (Kaikini & Paragaonkar, 1969). In Egypt, buffalo heifers exhibit first oestrus after the age of 13 months (Hafez, 1955). Age at puberty of buffalo heifers in the Philippines varies between 26 and 29 months (Villegas, 1930). Female buffaloes in Cambodia attain puberty at 3 years of age, whereas cattle heifers in that country achieve this physiological status some 6 months earlier (Baradat, 1949). Buffaloes in Azerbaijan exhibit first oestrus at 23 years of age, but with good feeding, puberty is attained earlier (Gorbelik, 1935). With the wide variation in reported age for puberty in buffalo heifers from different countries, it is obvious that wide variations will be found in age of conception and the age at first calving. From available reports it appears that, in general, buffalo heifers are not bred before they are 2.53 years of age. More commonly buffalo heifers are put to the bull at 3.5 years or later.

Oestrus, Oestrous Cycle and Ovulation

Oestrus in buffaloes shows marked variations. This could be due to differences in breed, environmental conditions and management. The signs of oestrus in river buffaloes from India, Pakistan and Egypt are less intense than in female cattle (Hafez, 1954; Ishaq, 1956; Luktuke & Ahuja, 1961). On the other hand, the symptoms of oestrus in the carabao of the Philippines are more obvious than in female cattle (Ocampo, 19391940). In 84% of cases oestrus in the Egyptian buffalo commences between 18.00 and 06.00 hours (Hafez, 1954), and in Indian buffaloes usually during the morning. According to some reports, mating desire in the buffalo ceases during the day and female buffaloes breed only at night (MacGregor, 1941; Cockrill, 1967). This may be true for wild or swamp buffaloes, but not for the river-type buffaloes of India and

Pakistan. Incidence of silent heat is high in buffaloes and many oestruses may go unnoticed unless great care is exercised in detection.

Breeding Behaviour

Bhat *et al*. (1983) observed that buffalo cows continue to come in heat regularly in all months, the highest being in October and the lowest in April (Table 8.9). There are no differences between months and between seasons with regard to the percentage of animals exhibiting oestrus and subsequent conception (Singhla, 1984). The view earlier held that there was seasonality in conception (Goswami & Nair, 1964; Rao & Rao, 1968, Roy *et al*., 1968) due to seasonal variation in oestrous cycle pattern, therefore, has to be rejected. The lower conception rate during summer months (April to September) is due to poor semen quality of buffalo bulls. Hot-humid months affect spermatogenesis of male buffaloes adversely. The use of frozen semen during these months is recommended to overcome lower conception rates.

In a study on Murrah buffaloes, oestrus during gestation was observed in 6.1 % of the animals and on average the oestrus symptoms were exhibited 108.4 ± 11.8 days post-conception (Luktuke & Roy, 1964).

Post-partum heat in the river buffalo when it appears early may manifest around 40 days following parturition, but in most instances appears after a period exceeding 100 days following the birth of the young (MacGregor, 1941; Shalash, 1958; Luktuke & Roy, 1964). The swamp buffalo in Malaysia exhibits first heat after parturition at about 65 days (MacGregor, 1941).

The length of the oestrous cycle of the buffalo is similar to that of cattle and is on average around 21 days (Shalash, 1958), but considerable variations in the length of the cycle can commonly be observed.

Fern-pattern formation by cervical mucus on drying is maximum during oestrus (Raizada *et al*., 1968; Sengupta & Sukhija 1988). Further, a high percentage of pregnancies results from insemination at oestrus, natural or induced, associated with typical fern-pattern formation in the cervical mucus.

Ovulation in buffaloes occurs subsequent to the cessation of oestrus as in the case of cattle and the time interval in the two species also appears to be similar (Shalash, 1958; Rao *et al*., 1960; Basirov, 1964).

The 'lutein' tissue that forms in the ovary following ovulation is white in buffaloes in contrast to the yellow colour observed in cattle.

Table 8.9 Monthly and seasonal occurrence of heat and conception rate in Murrah buffaloes. (*Source*: Bhat *et al*., 1983.)

Month of insemination	Heat (%)		Conception rate (%)	
January	8.8		26.0	
February	8.3		26.2	
March	7.2	25.2b	23.6	23.6b
April	5.9		19.6	
May	7.4		19.8	
June	7.4	24.8c	16.2	19.6c
July	7.1		17.3	
August	7.2		18.2	
September	8.1	28.6d	21.2	22.0d
October	13.1		24.3	
November	10.3		28.3	
December	9.2	28.8a	24.9	26.5a

a Winter (November to January); b spring (February to April); c summer (May to July); d autumn (August to October).

Gestation Length

The gestation length in buffaloes is somewhat longer than in cows, with a range between 299 and 346 days (El-Sheikh, 1967; Joshi *et al*., 1969). Mean gestation length (± S.D.) for Lanka buffaloes (316.3 ± 6.5 days) is significantly longer than that for Murrah buffaloes (309.9 ± 6.5 days) (Perera & de Silva, 1985). However, within each breed, the mean gestation length for males and females is very similar.

The average gestation period for river buffaloes in India and Pakistan is around 307 days. Buffaloes in Egypt carry their young a week or 10 days longer. The gestation period of the swamp buffalo is considerably longer than that of the river buffalo and lasts for 330340 days (MacGregor, 1941; Hua, 1957).

Ghanem *et al*. (1955) observed significant difference in length of gestation between paternal and maternal halfsibs and fullsibs. The heritability estimate for gestation length is 0.32 ± 0.02 (Joshi *et al*., 1969) in Murrah and 0.32 ± 0.13 (Ghanem *et al*., 1955) in Egyptian buffaloes.

Age at First Calving

A large variation exists in age at first calving across the breeds, it being highest in village buffaloes (Amble *et al*., 1958; Chhikara *et al*., 1978). The averages in Murrah and Nili-Ravi is 4044 months (Sreedharan & Nagarcenkar, 1978; Johari & Bhat, 1979b; Reddy, 1980), while that in Egyptian buffaloes was around 40 months (El-Sheikh, 1967; Alim, 1978). In Surti, Bhadawari and Nagpuri buffaloes, the age at first calving is slightly higher, 4654 months.

Month/season of calving has non-significant effect on age at first calving (Rathi *et al*., 1971; Johari & Bhat, 1979b; Dutt & Taneja, 1994). Differences between farms and years/periods for age at first calving are significant (Sharma & Singh 1978; Johari & Bhat, 1979b; Reddy, 1980; Dutt & Taneja, 1994). The farm differences could also be genetic in nature due to differences in genetic merit of sires used at these farms.

The heritability estimates for this trait varies between 0.12 and 0.34 (Reddy, 1980; Mangrurkar & Desai, 1981; Gurung & Johar, 1982; Kalsi & Dhillon, 1982). Dutt & Taneja (1994) reported it to be 0.53 ± 0.21 and 0.43 ± 0.08 respectively. Large differences in heritability estimates are due to differences in number of sires used, number of progeny per sire and variation between individuals within halfsib groups apart from differences in genetic merit of sires used in these herds.

Low phenotypic correlations between age at first calving and first lactation milk yield have been reported by various workers (Dutt *et al*., 1965; Tomar & Desai, 1968; El-Arian, 1986). However, Dutt *et al*. (1965) reported negative phenotypic association between age at first calving and milk production up to 6 (-0.74), 8 (-0.55) and 10 years (-0.46) of age. Low and negative phenotypic correlations between these two traits were also reported by Rathi *et al*. (1971) and Gogoi *et al*. (1985). The genetic correlations between these two traits were reported to range between -0.98 and 0.13 by Gogoi *et al*. (1985) and El-Arian (1986). Most of the estimates, however, had high standard errors. The negative genetic association between these two traits suggested that decrease in age at first calving would significantly increase the milk yield.

Service Period

The average first service period in Murrah buffaloes is 115230 days with an overall average of 132 days (Kohli & Malik, 1960; Goswami & Kumar, 1968; Kanaujia *et al*., 1974; Johari & Bhat, 1979b; Reddy, 1980; Jain & Taneja, 1984). The average first service period is 201 days in Nili-Ravi, 193 days in Bhadawari and 198 days in Egyptian buffaloes (Ragab *et al*., 1956; Sharma & Singh, 1978; Reddy & Taneja, 1984). In general, the service period in Murrah buffaloes at well-organized farms is much lower than in other breeds.

Significant farm and year/period differences for service period were reported by Kanaujia *et al*. (1974), Johari & Bhat (1979b), Reddy (1980) and Reddy & Taneja (1984). Reddy (1980) observed that average first service period was lower (132142 days) in July to November calvers than

in December to April calvers (203239 days). This suggested that buffaloes calving during December to April months should be carefully watched for heat in order to reduce the service period.

The heritability estimates for service period are, in general, low and range between 0.08 ± 0.06 and 0.22 ± 0.28. The phenotypic correlations between service period and milk yield are 0.16 and 0.55 (Singh *et al*., 1958; Kohli & Malik, 1960; Basu & Ghai, 1978; Reddy, 1980). The positive and significant correlations suggest that higher milk yield is associated with longer service period.

Dry Period

The averages of first dry period in Murrah buffaloes range from 153 to 217 days (Jawarkar & Johar, 1974; Gurnani *et al*., 1976; Kanaujia, 1978; Reddy, 1980; Jain & Taneja, 1984) with an overall average of 160 days. Chaudhary & Shaw (1965) reported much shorter first dry period of 98 days in Pakistan's Nili-Ravi buffaloes whereas a longer dry period (202 days) for this breed was reported by Reddy & Taneja (1984). Average dry period pooled over the lactations is 156.4 (Singh & Desai, 1962) in Bhadawari, 134.2 (Hadi, 1965) in Marathwada and 129.7 days (Kadu *et al*., 1978) in Nagpuri buffaloes. In Egyptian buffaloes, it ranges from 200 (Alim, 1978) to 296 days (Alim & Ahmed, 1954).

The variation between farms, between years and between months influenced dry period significantly. The average dry period for July to November calvers (145180 days) is lower than for December to April (191237 days) calvers (Reddy, 1980).

Jawarkar & Johar (1974) estimated the heritability of the first four dry periods as 0.20, 0.01, 0.20 and 0.02, respectively, in Murrah. In Egyptian buffaloes, Asker *et al*. (1953) estimated the heritability of dry period as 0.18. Kumar (1984) reported the heritability estimate to be around 0.0 to 0.7. Most of the estimates reported had high standard errors and suggested that the trait might be improved through management.

Calving Interval.

Reports on calving interval in the buffalo present very widely differing data. Except for a report from Italy in which an interval of less than 400 days is indicated, most of the other reports give considerably longer intervals. Short calving intervals, as reported from Italy, possibly indicate a better plane of nutrition and management of the herds. There are some reports which indicate that those buffaloes which calve at an early age have a relatively shorter calving interval than those which are late calvers (Alim & Ahmed, 1954; Salerno, 1960). Seasonal difference in calving interval has been reported in Murrah buffaloes, and it has been observed that in the animals which calve between June and November the average interval is 428.7 days, but in buffaloes calving between December and May the interval is 507.1 days (Singh *et al*., 1958).

The first calving interval in Murrah, Nili-Ravi and Egyptian buffaloes varies between 479 and 508 days (Alim, 1978; Johari & Bhat, 1979b; Reddy & Taneja, 1984). The overall calving interval, however, is lower (430457 days) than the first calving interval (Lall, 1975). Patro & Bhat (1979b) reported a decline of about 95.2 days in calving interval from first to seventh lactation. Basavaiah *et al*. (1983) reported the average first calving interval to be 583.3 days in Surti buffaloes.

Farms/years/periods have significant effects on calving interval (Basu & Ghai, 1978; Johari & Bhat, 1979b; Reddy, 1980; Kumar, 1984; Singh & Yadav, 1986). Month/season of calving also influences this trait significantly (Gurnani *et al*., 1976; Basu *et al*., 1978; Reddy, 1980; Kumar, 1984; El-Arian, 1986; Singh & Yadav, 1986).

Most of the heritability estimates reported for this trait are low and non-significant. The phenotypic correlations between first calving interval and first lacatation milk yield (300 days) range from 0.20 to 0.38 (Basu & Ghai, 1978; Basu *et al*., 1978; Reddy, 1980; Gupta, 1988). These significant correlations suggested that buffaloes with higher lactation yield would have a longer calving interval. Such a phenotypic association was expected since prolonged calving was di-

rectly related to feeding, management and heat detection practices. With good management, it should be possible to produce a calf a year from a buffalo although two in 3 years is the norm.

Estimates of repeatability and heritability of calving interval in the buffalo by several workers suggest that the genetic component of this attribute is very small and hence selection for a shorter calving interval is not likely to be rewarding.

Twinning

Twin births in the buffalo have been reported from Egypt, Italy and India. The frequency of twin births in Indian buffaloes is considerably lower (0.06%) than those in Egypt (0.20.6%) and Italy (0.3%). Cockrill (1970), however, reported a high incidence of about 1% of twinning in Surti buffaloes at Anand in India. The relatively higher incidence of twinning at Anand is attributed by Cockrill to the practice followed in that area of giving two inseminations within the oestrous period.

Artificial Insemination

Artificial insemination (AI) has been used as a breeding tool on a field scale so far only in a few buffalo-rearing countries. It has been practised on the largest scale in India where it is claimed that the first buffalo calf in the world bred by means of AI was born in the Allahabad Agricultural Institute on 21 August 1943.

The male buffalo can be trained more easily than male cattle for donating semen by artificial service. The buffalo is less choosy concerning the teaser and readily mounts an anoestrous female or even a male buffalo in the service crate. Coat colour or the physiological status of the female buffalo in the service crate does not alter the reaction time of the buffalo bull (Prabhu & Bhattacharya, 1954; Prabhu, 1956). The thrust given by male buffaloes during service is less vigorous than by male cattle. As in the case of male cattle, collection in the artificial vagina is also the most convenient method of obtaining semen from the buffalo. However, temperature of the artificial vagina needs to be modified suitably. With the temperature of the artificial vagina reaching 41°C there is bursting and breaking of buffalo spermatozoa, but a temperature of 39°C causes no damage to the cells (Mahmoud, 1952). Although it is possible to collect semen from the buffalo by the massage technique, the animal is less responsive to this method of ejaculation than male cattle, and also requires a longer period for training. The semen collected by this method is relatively poorer in quality. The capillaries of the rectal wall are more fragile in the buffalo than in cattle and hence manipulation through the rectum while massaging must be done with great care as otherwise bleeding may result as a consequence of the breaking of the capillary vessels. Electro-ejaculation from the buffalo, although successful, is not likely to come into general use in the near future.

Morphological characteristics of the spermatozoa of the buffalo and cattle differ. MacGregor (1941) was possibly the first to report that the head of the buffalo spermatozoon is more rectangular than that of male cattle and that the stained portion of the head is also slightly narrower in the former species. According to Rao (1958) spermatozoa of the buffalo possess distinct morphological characteristics by which they can be readily differentiated from spermatozoa of other domestic animals. Comparative morphology of the spermatozoa of Egyptian buffaloes and indigenous cattle can be seen in Table 8.10.

The morphology of spermatozoa changes with the age of the buffalo (Venkataswami & Vedanayagam, 1962) and with ageing in different diluents.

Unlike cattle semen which has a yellowish tinge, the semen from healthy buffalo bulls is milky white or milky white with a light tinge of blue (Shukla & Bhattacharya, 1949; Mahmoud, 1952). Cattle semen gives a colour reaction of various shades with DOPA (34-dihydroxyphenylalanine) (Mukherjee, 1964), but such a reaction is not detected with buffalo semen.

Volume, sperm concentration, initial motility and speed of travel of spermatozoa are generally lower in buffalo than in cattle semen.

Table 8.10 Comparative morphology of the spermatozoa of buffaloes and cattle. (*Source*: Mahmoud, 1952.)

Spermatozoa measurements	Buffaloes			Cattle		
	Mean (µm)	SD (µm)	CV (%)	Mean (µm)	SD (µm)	CV (%)
Head length	7.436	0.442	5.9	9.126	1.326	14.5
Head breadth (anterior)	4.264	0.520	12.3	4.732	0.494	10.4
Head breadth (posterior)	3.172	0.442	14.0	2.730	0.520	19.4
Ratio head breadth (anterior) to head breadth (posterior)	1.340	0.330	24.8	1.790	0.320	1.7
Neck	0.442	0.208	47.1	0.650	0.338	51.5
Length of middle-piece	11.648	0.936	7.9	12.558	0.624	4.9
Breadth of middle-piece	1.092	0.286	26.2	1.006	0.268	26.8
Length of tail	42.82	3.042	7.1	46.280	6.084	13.2

SD = standard deviation; CV = coefficient of variation.

Compared to cattle spermatozoa, the spermatozoa of the buffalo have an inherently poorer metabolic activity as judged by oxygen uptake and fructolysis. Variation in semen quality due to changes in the climate is also more pronounced in buffaloes than in cattle, as evidenced by changes in the respirometric activity of spermatozoa.

The depressing effect of the phosphate ion, and the stimulating effect of the chloride ion on the oxygen uptake pattern, as can be found in cattle spermatozoa, are not observable in buffalo sperm cells. This would suggest that either the influence of certain ions like phosphate and chloride on aerobic metabolism of buffalo sperm cells is intrinsically different from that of their effect on cattle sperm, or that the seminal plasma of the buffalo has properties which in some way obliterate the specific effects of the chloride or phosphate ions on oxygen utilizations *in vitro* (Sinha *et al*., 1966). The work of Roy *et al*. (1960) lends experimental support to the second hypothesis.

Roy *et al*. (1960), based on the comparative study on the semen biochemistry of buffalo and cattle (Table 8.11), observed that significantly higher concentration of calcium, esterified phosphate and the phosphate-splitting enzymes in buffalo semen create conditions that adversely influence the viability of spermatozoa in stored semen.

Several of the diluters, which proved very satisfactory for extension and storage of cattle semen, did not give as satisfactory results when used for buffalo semen. Egg-yolk phosphate buffer (EYP) has proved unsuitable for use with buffalo ejaculate. Egg-yolk citrate (EYC) is fairly satisfactory for dilution and storage of buffalo semen.

Kampschmidt's glucose sodium bicarbonate egg-yolk extender (with or without addition of sulphamezathene), appeared to be satisfactory for AI of the buffalo. Higher fertility results have also been reported with the use of Kampschmidt's diluent (Gokhale, 1958). Citric acid whey (CAW) is effective as diluent for storage of buffalo semen at refrigeration or deep-freezing temperatures. The spermatozoa in CAW are extremely sensitive to the pH of the diluent and sperm motility is maximal at pH 6.8.

Very satisfactory results have been reported from Pakistan with the use of homogenized milk as a diluent for buffalo semen.

Frozen Semen Technology

Deep freezing of buffalo semen is now the routine method of choice in many countries. Although efforts to deep-freeze buffalo spermatozoa by the conventional dry ice-alcohol method started as early as 1955, the real break-through came in 1973 when vapour freezing

Table 8.11 Differences in some chemical attributes of buffalo and cattle semen. (*Source*: Roy *et al*., 1960.)

Constituent	Buffalo	Cattle	Statistical
	(mg/100 µl semen or seminal plasma)		
Total reducing substances	700 ± 52	769 ± 42	
Fructose	355 ± 17	611 ± 39	**
Calcium	40 ± 2	25 ± 5	**
Chloride	373 ± 55	249 ± 26	*
Inorganic phosphate	6.4 ± 0.6	5.9 ± 0.5	
	(6.3 ± 0.4)	(5.6 ± 0.4)	
Acid-soluble phosphate	72 ± 3.9	29 ± 3.2	**
	(64 ± 2.2)	(27 ± 2.9)	**
Total phosphorus	103 ± 8.9	74 ± 2.5	**
	(95 ± 7.2)	(42 ± 4.8)	**
Acid phosphatase activity	308 ± 44	145 ± 11	**
	(307 ± 41)	(167 ± 11)	**
(Bodansky unit)			
Alkaline phosphatase activity	252 ± 37	134 ± 14	*
	(266 ± 42)	(152 ± 18)	*
(Bodansky unit)			

Figures in parentheses indicate values in seminal plasma.
*$P < 0.05$.
**$P < 0.01$.

technique was used with good freezability and fertility of frozen semen (Roy & Bhat, 1973). Of the wide assortment of extenders tried later, in terms of post-thaw motility and fertility, Tris-yolk-glycerol was found to be most effective. This extender is prepared by first preparing buffer solution of the following chemical ingredients:

Tris 30.48 g, citric acid 17.00 g, fructose 12.52 g, distilled water 840.00 ml.

This buffer is mixed with yolk and glycerol in the following proportions:

Tris buffer (as above) 740 ml, egg yolk 200 ml, glycerol 60 ml, total 1000 ml.

The optimum level of glycerol in the extender media appears to be 6.5 to 7.0% when used as the sole cryoprotective agent, but a lower level of glycerol is compatible with other cryoprotective agents like lactose or raffinose. The minimum cooling and equilibration time consistent with good freezability was about 6 h. Because of sheer simplicity and convenience, the liquid nitrogen vapour freezing method has become most popular.

Today 0.25 ml straws are used for freezing the semen. The sperm count is maintained at an optimum pre-freezing level of 4045 million live sperms. The mini-straw freezing has a slight advantage over the medium straws in survival rates obtained after freezing.

In using egg yolk lactose diluent, the conventional pattern of freezing consists of dilution of semen in glycerol-free fraction first, cooling to 1015°C, adding glycerol fraction in stages, then loading in straws, equilibrating for 45 h and freezing. When frozen by this method, buffalo semen in many instances cannot stand the addition of a second fraction after cooling. To overcome this, citrate diluent containing lactose with 6.5 to 7% glycerol is used to dilute the semen just as in the case of tris diluent. Among the diluents described, tris diluent gave the best survival rate as compared with others. As such this diluent is being used both for chilled and frozen semen.

In buffalo frozen semen technology, one shortcoming is the absence of any critical study

to determine the minimum number of sperms required per insemination dose for optimum fertility. The current dose of 50 × 106 total sperms or 2025 × 106 motile sperms/straw/ampoule is more than double the minimum number of motile sperms required for successful conception in cattle. The inherent level of fertility of the bull also needs to be considered. Another important lacuna is the absence of any systematic information on storability of frozen semen and maintenance of fertilizing ability on a long-term basis.

Rectovaginal technique is preferable for inseminating the female buffalo when suitably trained technicians are available; if not, speculum method may be used, with adequate sanitary precautions. It is generally accepted that the site of deposition of semen should be the same as in female cattle. The speed of travel of spermatozoa in the reproductive tract of Indian female buffaloes is about the same as that reported by Van Demark & Hays (1954) for female cattle. Spermatozoa reach the anterior third of the fallopian tubes in 3 minutes and 20 seconds following AI.

Conception Rate

Information available on conception rate in buffaloes either by natural service or by AI is very limited. Furthermore, different workers have assessed conception rate following different methods under widely differing husbandry practices. Consequently, it is very difficult, if not impossible, to draw any definite general conclusions. Conception rates in Indian buffaloes vary from 50 to over 90%. The average number of inseminations required per conception is 1.56. Fertility is ascertained by rectal palpation and by calving results.

The average number of services per conception in Murrah buffaloes is 1.6 to 3.1 (Luktuke & Roy, 1964; Singh & Dutt, 1964; Basu *et al*., 1978). In Surti, the average number of services per conception is 1.67 (Shukla *et al*., 1970), and in Egyptian buffaloes 1.51 to 2.10 (Ragab *et al*., 1956; Ahmed & Tantawy, 1959). In general, heifers take more services than pluriparous buffaloes (Ragab *et al*., 1956; Rao *et al*., 1973; Basu *et al*., 1978).

Hafez (1953) found the average number of services required per conception in the buffalo to be 1.46. He also noticed that 55.6% of the animals conceived following the first service.

A conception rate of 72% was not uncommon in buffaloes bred by AI in Pakistan (Rife, 1959).

Embryo Transfer Technology

Successful superovulation in cattle was reported in 1940 and the first calf produced as a result of egg transfer was born in Wisconsin in 1951. Research on embryo transplantation in buffaloes is a fairly recent development. The initial success of Drost *et al*. (1983) in the United States, who pioneered application of the technology to buffaloes, was soon followed with the successful birth of buffalo calves in Bulgaria (Vlakhov *et al*., 1985) and India (Misra *et al*., 1988; Madan *et al*., 1990). Studies on superovulation among buffaloes have also been carried out in Thailand (Thungtanawat *et al*., 1981; Chantaraprateep *et al*., 1989a,b; Techakumphu *et al*., 1989; Venitkul, 1989), Bulgaria (Karaivanov *et al*., 1987; Alexiev, 1989), Malaysia (Jainudeen, 1989), Pakistan (Mehmood *et al*., 1989) and India (Madan *et al*., 1990; Taneja *et al*., 1990; Misra *et al*., 1990,1991; Singla *et al*., 1992). The first buffalo calf by this method was born on 22 December in 1987. Knowledge about the reproductive physiology of buffaloes is scanty. Embryo transfer can be instrumental in opening ways for more accurate understanding of numerous unknown aspects of reproduction. Information on superovulation response, recovery rate of embryos and their quality vis-à-vis the endocrine picture of both superovulated and normal cyclic animals, needs to be gained for better understanding of buffalo production.

The intricate factors responsible for biological peculiarities of buffaloes are manifold. The lower reproductive potentiality of buffaloes can be confirmed from the very stock of primordial follicles in the ovaries. The average number of primordial follicles is 19 000 in Nili-Ravi buffaloes and 12 000 in Surti buffaloes. These values are much lower than those for cattle (60 000100 000) and reflect the lower reproductive potentiality of buffaloes.

Two types of gonadotrophins have commonly been used to suprerovulate donor buffaloes. These are pregnant mare serum gonadotrophin (PMSG) and follicle-stimulating hormone (FSH), usually administered during the mid-luteal phase (914 days) of the oestrous cycle. The most common method of superovulation is the injection of a single dose of PMSG (3000 IU) during the mid-luteal phase of the oestrous cycle followed 48 hours later by a leutolytic dose (500 µg) of prostaglandin (PG a2). Follicle-stimulating hormone and prostaglandins are used to superovulate buffaloes according to treatment regimens developed for cattle. To obtain greater superovulatory response, doses of FSH ranging from 40 to 70 mg have been used as two injections in a day. The percentage of donors exhibiting oestrus was high (about 80%) in both PMSG and FSH groups. But the prostaglandin standing heat intervals established in the PMSG-treated group was significantly longer than in the FSH-treated group. The percentage of non-ovulated follicles following PMSG treatment was high. The average number of good-quality embryos per buffalo donor was not high on either PMSG or FSH treatment. A good response always depends upon a good corpus luteum and an optimum level of progesterone at the beginning of the treatment. In buffaloes the picture is different because of the absence of prominent luteal tissue. This problem can be mitigated by implantation of an artificial corpus luteum, like Synchromate B, before initiation of treatment. Priming of ovarian tissue at an early stage of the cycle by FSH may resolve the rate of response by recruitment of a greater proportion of follicles that become atretic at the end of the first follicular wave.

It is difficult to determine the exact number of corpora lutea on the small ovaries of buffaloes, particularly when it exceeds five or six, or when they are accompanied by several large tense follicles, leading to overestimation of response. Moreover, in buffaloes the corpus luteum is small, more deeply embedded and fused; it generally has a less pronounced papilla. So far the results of embryo recovery from buffaloes have been frustrating. This may be attributed to several factors. Overstimulation of ovaries can lead to a failure of the fimbriae to envelop the ovary at the time of ovulation. The problem of fluid recovery (2060%) may be due to a more tortuous nature of the cornua.

There has been a steady progress in terms of superovulatory responses, embryo recovery and pregnancy rate following embryo transfer among buffaloes. From the early recovery rate of 0.6 transferable embryos, currently 2.02.4 transferable embryos are recoverable in different farms with altered superovulation protocols. Folltropin and super-ov among many compounds have comparatively given better results both in terms of the follicles developed and ovulated, and the embryos recovered. The lower number of follicular population and poor follicular development, as revealed through real-time ultrasound scanning, explains the lower ovulatory response. The growth rate of the largest follicle and time of ovulation post-PGF have also shown great variability in animals. Endocrine studies suggest that unovulated follicles contribute massive quantities of oestrogen along with progesterone. High prolactin levels in buffaloes during summer months are also associated with poor follicular maturation. In spite of some problems related to buffalo embryo transfer, the basic embryo transfer technique has been adopted with success resulting in over 1000 pregnancies/calves.

Buffalo embryo transfer is difficult because of different physiology and anatomy of this species, namely the total number of follicles in the ovary, the superovulatory response, the behavioural oestrus, development of the embryo and coiled uterine horns. This technology has to be made effective in buffalo, by undertaking more intensive studies on freezing, microsurgery of embryos, oocyte culture and *in vitro* fertilization.

Embryo transfer is often viewed as a counterpart of artificial insemination, where a superior animal, i.e. a donor, is superovulated; more than one embryo at a time can be recovered and transplanted into recipient females to increase the progeny number per female. The technique of AI has made it possible to increase the utility of males. It has also become possible to increase the influence of the genetically superior females by the use of embryo transfer. Introduction (see Chapter 4) of a multiple ovulation and embryo transfer (MOET) scheme (Bhat, 1977, 1985) will increase the selection intensity through increased progeny per buffalo per annum in the herd.

MOET schemes allow progeny testing of both males and females, and can increase the genetic gain per annum over what is possible by using artificial insemination alone. More sires can be tested within a short period, and at low cost, by using the semen of the male to be tested on a few donors and transferring the embryos recovered to the required number of recipients.

In vitro *Fertilization of Buffalo Oocytes*

In order to by-pass the problem of low embryo production rate, an *in vitro* fertilization technique has been developed. A method was developed for ovaries obtained from slaughterhouses. The recovery rate of good cumulus-complex oocytes was 0.42. Only 40% of oocytes reached metaphase which is the maturation stage of the oocytes.

In vitro capacitation of buffalo spermatozoa was done by exposure to heparin for at least 7 hours for maximal response in fertilization.

All mature oocytes with an expanded cumulus mass were introduced into 100µl droplets of capacitated spermatozoa suspension for 6 hours in a CO_2 incubator at 38.5°C.

Initial experiments on the fertilization showed that out of 131 mature oocytes kept for fertilization only 29.8% were fertilized. Only 0.76% reached up to the morula stage and 1.52% up to blastocyst stage. Most of the oocytes were arrested at pronuclei formation stage (11.45%). After making modifications in the technique it was possible to increase the fertilization and cleavage rates. Out of 174 mature oocytes about 55% oocytes were fertilized, 2.87% were at morula stage and 0.57% at blastocyst stage. The technique was further improved and about 80% oocytes were fertilized. Out of 185 mature oocytes, 14.6% reached morula stage and 8.10% blastocyst stage.

IVF Embryo Transfer

Twenty-two IVM/IVF embryos at the stage of morula/blastocyst were transferred to the recipients. Out of these, six pregnancies were confirmed and two calves have already been born including 'Pratham', the world's first *in vitro* fertilized buffalo calf.

Nutrition

The vast majority of buffaloes are reared in regions of the world that are poorly developed and they are owned by farmers with hardly any capacity for financial investment. In the regions where buffaloes abound there is considerable quantitative deficiency of feeds and fodders, and available foodstuffs are possibly qualitatively deficient. In this situation it becomes very necessary to search for non-conventional materials that can be utilized as feeds to make good the quantitative deficiency and to evolve processes by which qualitative deficiencies of feeds can be rectified.

One basis for progress in livestock development is research, as this provides the necessary data for the formulation of effective developmental programmes. In order to prepare such a programme concerned with the nutrition of the buffalo and to ensure the supply of the optimal nutritional requirements of buffaloes of different ages and levels of production in different regions, two things are absolutely necessaryinformation on the nutritional composition of the locally available feeds and fodders and knowledge of the alimentary physiology of the buffalo. As the nutritional physiology of cattle has been investigated in great detail, and as cattle and buffaloes are similar in many respects, it would be profitable to know if their alimentary physiology differs and, if so, in what details. Unfortunately, in many of the buffalo-rearing countries the organizational base for research in animal nutrition is weak and inadequate. As a result, very large

gaps exist at present in knowledge relating to different aspects of the nutrition of buffaloes.

There has been a great scientific interest in studying the comparative performance in the utilization of nutrients in cattle and buffaloes, specially when there are distinct physiological differences between the two species in rumen movements, fluid volume in the rumen, and the rate of passage of digesta, etc.

Voluntary Intake of Dry Matter.

Buffaloes consume 73.1116.9% of dry matter consumed by cattle. Factors like various experimental treatments, composition of feed, frequency of feeding as well as processing of feeds are responsible for these differences. In lactating buffaloes (Sebastian *et al*., 1970) consumption is 14% less than in lactating cattle.

Comparative Digestibility Coefficients

Buffaloes are superior to cattle in their ability to digest the organic nutrients. Generally buffaloes digest 25% more of each nutrient than cattle. In the majority of the studies, however, the difference of 25% in the digestibility between species was not statistically significant (Chaturvedi *et al*., 1973).

Fluid Volume in the Rumen

Various *in vitro* experiments conducted with rumen liquor showed the superiority of buffaloes over cattle in utilizing cellulose (Ichhponani *et al*., 1971a) and other cell-wall constituents. Cellulose digestion was faster when filter paper was incubated with rumen liquor of buffalo than incubated with rumen liquor of cattle, thus showing more cellulolytic activity of the rumen. This led many workers to conclude that buffaloes are capable of utilizing inferior quality roughages in a better way than cattle. The difference in the digestibility between the species was observed in all categories of animals such as growing, non-producing adult and lactating animals. Consumption of a lesser quantity of dry matter by buffaloes when compared to cattle might be responsible for the slightly higher digestibility observed in buffaloes (Grant *et al*., 1974). The slower rate of passage of food through the reticulo-rumen of buffaloes was also attributed to be one of the reasons for higher digestibility of crude fibre in buffaloes since this mechanism would provide for better and longer exposure of the ingesta to microbial digestion in the rumen.

The concentration of total volatile fatty acid (TVFA), ammonia and bacterial nitrogen is higher in buffalo rumen liquor than in cattle rumen liquor (Ichhponani *et al*., 1971a). It is, however, difficult to conclude the superiority of species from the mere knowledge of the concentration of metabolites in the rumen liquor since the concentration at any time depends upon a balance between production and removal. The removal may either be through absorption, onward passage to the omasum or mutual use of metabolites by various species of rumen microorganisms. It is therefore necessary that care is taken while interpreting the results of the concentration of rumen metabolites, since the slower rate of passage of the ingesta in buffalo might be responsible for a higher concentration of volatile fatty acid (VFA), bacterial nitrogen or ammonia nitrogen, etc. The higher concentration of certain electrolytes in the rumen liquor of buffaloes such as potassium and calcium (Prasad & Raghavan, 1973) might also be due to the same reasons.

The basic physiological difference in the flow rate of ingesta might also alter the rumen environment so as to influence the utilization of the food. For example, blood urea concentration of the growing buffalo calves below 2 years of age is almost twice (Mehra *et al*., 1976) that of the cow calves. Higher blood urea is parallel to higher ruminal ammonia concentration in the rumen of buffaloes. Higher ammonia level is either due to the low rate of passage of ingesta or the higher proteolytic activity of microbes. Ammonia concentration in cattle and buffaloes has always been more than 11 mg per 100 ml of strained rumen liquor (SRL). It was suggested that higher blood urea concentration in buffaloes can be effectively recycled and used in times of deficit, though this has never been confirmed experimentally. One significant difference between species is a narrower ratio of acetate to propionate in rumen liquor of buffaloes than in cattle (Ichhponani & Sidhu, 1965a,b; Singh & Ranhotra, 1970). This difference may be due to differences in the rate of passage, since actual production rates of propionate were lower or equal to that in cattle. Apart from the concentration of these metabolites, the actual production rates of VFA determined by using isotope dilution techniques (Chaturvedi *et al*., 1973) did not reveal any significant difference between species.

Buffaloes are superior to cattle in nitrogen retention (Sebastian *et al*., 1970). When the intake of nitrogen is approximately the same in both the species, buffaloes show better retention of nitrogen than cattle. The reason for this is not obvious, since the digestibility of crude protein in many instances is only slightly higher in buffaloes. The higher balance of nitrogen has not been reflected in the higher growth rate in the buffaloes. This higher nitrogen balance may perhaps be due to the inherent capacity of buffaloes to hold more of non-protein nitrogen (NPN) in their blood.

Rumen Fermentation

The salient species variations between the fermentation processes of buffaloes and cattle were investigated at an early stage (Ichhponani *et al*., 1962; Singh *et al*., 1968). Total volatile fatty acid concentration in the rumen of buffaloes was significantly greater than of cattle on rations containing berseeem plus wheat straw plus concentrate (Ichhponani & Sidhu, 1965a) and green pearl millet and cowpea mixture (Ichhponani & Sidhu, 1965b). The buffalo rumen ecosystem was favourable for the establishment of a significantly higher number of microiodophils (including *Oscillospira guillermondi*) than that of cattle (Langar *et al*., 1968) and such types of microorganisms have been considered as protein synthesizers from NPN. Confirmation of this variation in the rumen ecosystem was obtained by transferring buffalo digesta, rich in *Oscillospira*, into the emptied cattle rumen and vice versa (Singh *et al*., 1968).

In vivo rumen metabolism studies using straw-green fodder mix based roughages showed that the buffalo rumen liquor had high-protein synthesizing activity and total and individual volatile fatty acid concentration superior to that of cattle. Better utilization of crop residues and NPN by buffalo was confirmed by feeding straw, supplemented with an isocaloric concentrate mixture having 0, 17, 35 and 50% digestible crude protein (DCP) substituted by urea-N (Langar *et al*., 1984). The nitrogen fractions of SRL showed significant differences ($P > 0.05$) in the protein-synthesizing activities and microbial counts of buffaloes and cattle (Table 8.12). The cellulose and acid detergent fibre (ADF) digestibilities were also significantly higher in buffaloes than in cattle.

The amino acid profile of the bacterial and protozoal fractions separated from the SRL showed quantitative differences in the proline, phenylalanine, diaminopimelic acid, cystine and methionine contents in the fractions collected from buffaloes and cattle. The buffalo protozoal fraction had also higher tyrosine content. With the increased urea intake, the sulphur amino acids content in the microbial fraction showed a decline. It suggested that NPN feeding affected the sulphur level of the ration thereby limiting the methioninecystine synthesis by the rumen microorganisms (Multani & Ahuja, 1985). In the late 1970s and early 1980s a series of *in vitro* and *in vivo* experiments were conducted to compare the production of biochemical entities in the rumen (Ichhponani *et al*., 1969a, 1972) and the utilization of nutrients (Ichhponani *et al*., 1969b, 1971a,b,c) in buffaloes and cattle. A comprehensive review (Ichhponani *et al*., 1977) of the results of these studies established that the buffalo was superior to cattle in many aspects like rumen fermentation pattern based on the type of microorganisms, and in the digestion and utilization of various carbohydrate sources, from simple starch to very complex cellulosic materials.

One major observation which has immediate field application relates to studies on the effect of diets on the microbial population and rumen

Table 8.12 Differential microbial counts in strained rumen liquor, rumen volume and nitrogen retention. (*Sources*: Langar *et al*., 1968; Langar *et al*., 1984.)

Species	Treatment T1	T2	T3	T4	Mean
	% urea replacing DCP of T1: 0	17	35	50	
	Oscillospira (×10/litre)				
Buffalo	84.20	74.80	63.90	117.74	85.20
Cattle	5.26	4.52	5.57	6.82	5.54
	Other Microiodophils (×10/litre)				
Buffalo	270.7	258.20	265.80	287.20	270.50
Cattle	220.3	234.60	221.60	223.30	225.00
	Protozoa (×10/litre)				
Buffalo	9.90	11.80	12.70	13.80	12.10
Cattle	8.54	7.43	7.38	6.21	7.39
	Trichloroacetic acid precipitable-N (mg/100 ml SRL)				
Buffalo	17.10	14.90	16.30	14.40	15.70
Cattle	15.00	11.90	12.10	13.30	13.10
	Rumen fluid volume (litres)				
Buffalo	36.40	33.40	32.40	34.20	34.10
Cattle	23.50	21.30	17.80	16.50	19.80
	Nitrogen retained (g/day)				
Buffalo	23.80	16.90	14.60	0.38	13.73
Cattle	15.00	6.48	10.43	-6.98	6.22

Main roughage = wheat straw. DCP = digestible crude protein.

metabolites in buffaloes. It revealed that the diet comprising wheat straw, green fodder, concentrates and mineral mixture sustained the highest population of rumen bacteria and protozoa (Salim Iqbal *et al*., 1992). Concentration of TVFA, ammonia nitrogen and amino nitrogen attained their peak levels within 24 h post-prandial period indicating optimal microbial activity in the rumen, whereas the diet containing only wheat straw exhibited least protozoal and bacterial count, decreased rumen metabolites and complete vanishing of *Epidenia* (Singh *et al*., 1992). This could be attributed to differences in the protein: carbohydrate ratio and mineral supplementation. Wheat straw and green fodder diet showed highest percentage of Holotrichs and maximum concentration of free amino acids in the rumen liquor. Dietary differences had a highly significant effect on the population of rumen microorganisms and the percentage of Holotrichs, *Entodinia, Diplodinia* and *Epidinia* (Singh *et al*., 1992).

The concentrations of iron, zinc, copper, cobalt and manganese were significantly higher in blood plasma, cerebrospinal fluid (CSF) and rumen fluids (RF) when animals were fed a diet consisting of wheat straw, green fodder and concentrate. These elements were at low levels when wheat straw only was fed. Dietary differences had a significant effect on the levels of trace elements. There was a positive correlation between blood and CSF. Interrelationship of these elements in the body fluids under different feeding regimens was highly correlated. A decreasing trend of trace elements in CSF revealed a quadratic relationship with blood and plasma (Singh *et al*., 1990).

Buffaloes thrive better than cattle on coarse fodders. This has given an impression that buffaloes are more efficient than cattle in digesting and utilizing crude fibre and cellulose. The present status of knowledge of the comparative alimentary physiology of the buffalo and cattle indicates that differences exist but that it is not possible to draw any definite conclusions as to whether one species differs from the other in any material manner in relation to digestion and utilization of nutrients in commonly used feeds and fodders, or if one species is superior to the other in digestive and metabolic functions.

On the basis of rumen studies, investigations were centred on the urea/uromol utilization, determination of energy values of forages, and energy and protein requirements of buffaloes.

Urea/Uromol Utilization

Experiments conducted on urea utilization with crop residues as basal roughage showed that buffaloes could tolerate higher levels of dietary urea than cattle (Kaushal *et al*., 1972; Malik & Chopra, 1980). In spite of a high capacity for dietary urea intake, chances of accidental ammonia toxicity were eliminated by developing a cooked ureamolasses complex named uromol (1:9 urea: molasses) reported first in 1974. This complex has above 50% bound urea and a slow rate of *in vitro* release of ammonia (Chopra *et al*., 1974). *In vivo* studies (Malik *et al*., 1978b) showed slow rumen degradation of uromol in the rumen, thereby resulting in a steady ammonia concentration for better microbial protein synthesis and fibrolytic activity on crop residues.

Comparative rumen metabolism, growth and lactation studies on buffaloes with concentrate supplements having groundnut-cake (GNC), uromol or ureamolasses at iso-nitrogenous levels showed that uromol was as good as GNC (Malik *et al*., 1978a,b). Use of uromol up to 65% of the total nitrogen in a concentrate supplement fed with straw resulted in higher crude fibre (CF) and cellulose digestibilities and nitrogen retention than that with ureamolasses. The steady release of rumen ammonia with uromol ration resulted in better synchronization on microbial protein synthesis and the nitrogen outflow, and the post-rumen availability of nitrogen was 9395% of intake with GNC and uromol ration as compared to only 78% observed from ureamolasses ration (Malik *et al*., 1978b; Malik & Chopra, 1978).

Feeding iso-nitrogenous levels of GNC or uromol-containing concentrate supplements resulted in comparable daily weight gains in buffalo calves as compared to low gains observed with ureamolasses (Malik *et al*., 1978a). Feeding uromol-containing concentrate supplement for 120 days to lactating buffaloes (Malik & Chopra, 1977) did not have any adverse effect. A long-term study, continued for two lactations with intervening dry pregnant periods, revealed that as compared to GNC or the uromol-fed group, the buffaloes fed on ureamolasses had a high plasma urea, weight loss and drop in milk yield in the second lactation (Langar *et al*., 1982). These results showed that urea fed alone or with molasses was inferior as compared to processed urea fed as uromol.

The problem of low shelf-life of cold uromol and its subsequent mixing with other feed ingredients was overcome by developing a uromolbran product (Malik & Makkar, 1979). This product, prepared by using urea, molasses and bran in the ratio of 1:3:5, had 36% DCP and 72% total digestible nutrients (TDN) and could substitute (w/w) oilcakes in a concentrate supplement. Based on these results the recommendations regarding feeding of this product to buffaloes are:

(1) Uromolbran mixture should form 15% of the concentrate ration (replacing 50% of the cake portion) for fast-growing (above 6 months of age) and high-milk-yielding buffaloes (peak yield 15 kg and above).

(2) For slow-growing and low-milk-yielding (peak yield 810 kg) animals the uromolbran mixture can form 30% of the concentrate supplement (replacing 100% cake).

Uromol-impregnated wheat straw (UIWS) as maintenance ration with 0.5 kg concentrate mixture could form maintenance ration for a mature buffalo (Kakkar *et al*., 1983).

Uromin Lick

The advantage of solidification of uromol on cooling was taken for developing a uromin lick. This lick comprises 400 g urea, 1200 g molasses

(boiled for 30 min), 600 g mineral mixture, 400 g salt, 600 g starch or maida, 400 g deoiled groundnut-cake and 400 g deoiled rice bran, mixed thoroughly and pressed to form a brick of about 4 kg; 2% bentonite being added as a binder. This brick can be kept in the feeding trough for licking. A growing calf licks about 0.5 kg of this brick daily and this provided a part of the crude protein requirements and almost the whole of the mineral requirements of the animals (Ahuja *et al*., 1986; Makkar *et al*., 1989).

Leucaena Lick

A lick containing *Leucaena* leaves (40%) has also been developed (Gupta & Malik, 1990) with the difference that it did not contain any conventional feed ingredients other than molasses. The composition of this lick on a per cent basis is: urea 10, molasses 35, mineral mixture 14, *Leucaena* leaf-meal 40 and acetic acid 1. These licks have been used in the Kandi area of the Punjab in India and other places where concentrates and good-quality green fodders are in short supply.

Use of Protected Proteins

Ruminants in general obtain a uniform quality of protein after microbial synthesis inside the rumen (Malik & Chopra, 1981). This microbial protein, at the time of peak production, sometimes limits the availability of energy and/or protein. To overcome this situation, protected or bypass proteins have been recommended. One of the methods used is 1% formaldehyde treatment of vegetable proteins or other proteins which after treatment can escape microbial degradation and will be directly available to the animal. Ration formulations containing formaldehyde-treated GNC gave a daily weight gain of more than 500 g in buffaloes (Malik *et al*., 1981). The use of a higher level of formaldehyde, or keeping the treated cake for a longer period, resulted in the over treatment of protein. This caused nitrogen starvation in the rumen of buffaloes. Addition of 12% urea, mixed in the concentrate mixture, helped to increase rumen microbial population and ultimately improved cellulose digestion. The effect of adding urea on a formaldehyde-treated cake-based ration is shown in Table 8.13.

Protein Requirements

The protein requirement of growing buffalo calves for achieving a daily weight gain of 500 g is given in Table 8.14 (Kakkar *et al*., 1991). Buffalo calves weighing 100300 kg required marginally lesser protein than that recommended by Kearl (1982).

Processing of Crop Residues.

Cereal crop residues alone cannot meet the maintenance requirements of the animal because

Table 8.13 Weight attained and live weight gain in periods I and II of formaldehyde treatment. (*Source*: Malik *et al*., 1981.)

Groups	Period I		Period II	
	Total weight gain (kg)	Daily weight gain (g)	Total weight gain (kg)	Daily weight gain (g)
GNC	73.3	479	75.7	501
TGNC	97.5	637	79.3	525
TGNCU	76.5	500	85.0	566

GNC = groundnut-cake, control group; TGNC = GNC treated with formaldehyde (1% formaldehyde treatment in period I and with 2% in period II); TGNCU = formaldehyde treated GNC + urea.

Table 8.14 Estimated DCP and CP requirements of buffalo calves.
(*Source*: Kakkar *et al*., 1991.)

Body weight of calves (kg)	DCP requirement (g/day)		CP requirement (g/day)
	Kearl (1982)	Estimated	
100	254	234	344
150	319	293	430
200	341	314	462
250	374	344	506
300	402	370	525

DCP = digestible crude protein; CP = crude protein.

of high lignification, low nitrogen and mineral contents. Several physico-chemical and biological pre-processes have been tried and tested on buffaloes for upgrading the nutritive value of crop residues.

Physico-Chemical Treatments

Wheat straw or bagasse (sugar cane residue after extraction) after treatment with (w/w) 2 and 5% sodium hydroxide, when fed with uromol as a nitrogen source, results in increased availability of metabolizable energy (ME). But in order to meet the total ME requirement for maintence of adult buffaloes (400500 kg weight), 600 g per day of cereal or cereal by-product supplement is required with untreated strawuromol ration. Processing using pure alkali is, however, uneconomical. An alkaline (0.81.0% alkalinity) keir boiling waste (KBW) effluent from textile industry, when used for treating cereal crop residues (3 litres/kg crop residue), improved the digestibility of treated material to the same extent as by treating with 3.0 (w/w) sodium hydroxide (Nagra & Langar, 1984).

Natural Fermentation

Fermenting straw only or stover (96.5%) with urea (3.5%) at 70% moisture could provide upgraded straw for animal feeding in only a 9-day period as compared to the 30-day period used earlier. Further, using the fresh, naturally fermented material as inoculum in the subsequent batches hastened the process to provide upgraded straw preparation within only 6 days (Gupta *et al*., 1984). Experiments on the 9-day natural fermentation when carried out with 40, 50, 60 and 70% moisture level, showed that 40% moisture level provided the straw preparation with a nutritive value close to that available with 70% moisture (Bakshi *et al*., 1987). These fermented straws provided enough nutrients for maintenance of buffalo calves.

Evaluation of Agro-Industrial By-Products As Buffalo Feeds

A large number of agro-industrial by-products have been evaluated as an alternate source of feed in buffaloes. Some of these by-products can be used with relative ease by the farmers themselves whereas others have to be processed before use. The latter involves biotechnological approach to first degradation of plant cell-walls in crop residues with a particular focus on lignocellulose breakdown using recombinant microbes to simple sugars; and second detoxification of growth depressants, antimetabolites and incriminating toxins from oil-cakes, oil-meals and other seed products after deoiling.

Some of the technologies which are currently in use are given below.

• *Corn steep fluid*. This is a by-product of the starch industry. It has 40% CP and 23% soluble sugars. Compared to urea, corn steep fluid as a nitrogen source in buffalo rations gives better rumen microbial protein yields (Virk *et al*., 1981).

• *Spent brewers' grain*. The fresh product from the brewery has 75% moisture and on a dry matter basis contains 18.8% CP, 14.6% DCP and 54.6% TDN. The dried brewers' grain can replace 50% of the concentrate supplement requirement of growing and milking buffaloes (Virk *et al*., 1981).

• *Potato waste*. There is about 7% wastage when potatoes are stored in cold stores. These discarded potatoes can be used as alternate energy source in the rations of buffalo calves (Makkar *et al*., 1984). The waste potatoes can be fed as such after chopping or with urea as a source of nitrogen. Potato waste contains 13% CP on a dry matter basis.

• *Poultry excreta*. Poultry droppings on wheat-straw-based poultry litter can be used in buffalo ration after processing (Malik *et al*., 1980; Ahuja *et al*., 1983). In a long-term experiment on buffalo heifers, poultry excreta with wheat straw was mixed at 27 and 37% levels in the concentrate mixtures after grinding. A groundnut-cake-based ration was used as a control. In poultry litter ration, energy intake was made good by additional feeding of concentrates. The experiment was continued until the heifers conceived. There was no adverse effect of feeding poultry-litter-based rations, digestibility and nitrogen retention being similar to those of the control group (Malik *et al*., 1980).

Rumen fermentation pattern and nutrient requirements of buffaloes are not the same as those of cattle. The buffalo is a better converter of NPN compounds into protein and in the digestion of crude fibre. Adoption for the buffalo of the feeding standards as recommended by the National Research Council of the United States or the Agricultural Research Council of the United Kingdom for cattle appears to be a good policy to follow, with a modified standard based on research results to be used whenever it is considered appropriate.

Production

Work

The buffalo has been used as a work animal for thousands of years. Its body build, enormous strength, docile temperament, amenability for easy training and capacity for long sustained work makes it an excellent animal to use for haulage and many kinds of agricultural work. The water buffalo is the classic work animal of Asia, an integral part of this continent's traditional village farming structure. Probably the most adaptable and versatile of all work animals, it is widely used to plough, level land, plant crops, puddle rice fields, cultivate field crops, pump water, haul carts, sleds and shallow draft boats, carry people, thresh grain, press sugar cane, haul logs, and much more. Even today, water buffaloes provide 2030% of the farm power in south China, Thailand, Indonesia, Malaysia, the Philippines, and Indochina. Millions of peasants in Asia maintain draught buffaloes. For them it is often the only method of farming food crops. As fuel becomes scarce and expensive in these countries, the buffalo is being used more frequently as a draught animal. In 1979 water buffalo prices soared in rural Thailand because of the increased demand.

Although Asian farms have been increasingly mechanized since the 1970s, it has often proved difficult to persuade the farmer to replace his buffalo with a tractor since the buffalo produces free fertilizer and does not require diesel fuel. Now there is renewed official interest in draught power. Because of demand for work animals, buffalo shortages have become a national development problem. Indonesia's transmigration schemes are also handicapped by shortages of animal power. For many small farmers the buffalo represents capital. It is often their major investment. Buffalo energy increases their productivity and allows them to diversify. Even small farms have work animals that, like the farmer himself, subsist off the farm. Tractors usually require at least 4 ha for economical operation, which precludes their use on most peasant farms. Further, the infrastructure to maintain machinery is often not readily available.

The working buffaloes (Figs 8.4 and 8.5) are slower in movement in comparison to oxen; they usually cover 3.2 km per hour against 4.86.4 km per hour by draught bullocks. However, the buffaloes can draw heavier loads than oxen (Fahimuddin, 1975). Liu (1978) and Nagpaul *et al*. (1984) studied the draught efficiency of crossbred cattle vis-à-vis zebu and buffalo bullocks for various farm operations like carting and ploughing. The pulse rate, temperature and respiration rate increased steadily after the start of work in all the categories of bullocks. The buffalo bullocks started showing signs of fatigue after 2 hours of work, whereas zebu and crossbred bul-

Fig. 8.4
Buffalo bullock drawing water.

Fig. 8.5
Buffalo bullock being used for cultivation.

locks did not exhibit these symptoms even after 4 hours of work. Season had a significant effect on rate of increase in temperature, pulse rate and respiration rate in these categories of bullocks. It was observed that buffalo bullocks during summer months covered a distance of 2193 m in 1 hour of carting as against 2682 m per hour by crossbred bullocks. In winter, buffalo bullocks covered 2768 m per hour as against 2645 m by crossbreds. It is essential that the draught capacity of various breeds of river and swamp buffaloes used for milk should be investigated. The improvement or otherwise in draught capacity as a consequence of selection for milk also needs to be investigated.

A survey by Cockrill (1968) revealed that in more than 20 Asian countries buffaloes provide the most efficient and the cheapest source of power. Both swamp and river buffaloes make good work animals, but for paddy cultivation in the rice-growing areas in Eastern Asia the swamp buffalo is unmatched for efficiency. They are used for ploughing the soil, for puddling the earth and harrowing the fields after flooding and for making the bed ready for planting the rice seedlings. The large hooves and great flexibility of the pastern and fetlock joints enable the swamp buffalo to work with ease in thick, muddy, water-logged paddy fields. Their productivity also makes them very well adapted for this kind of work in slush and mud. It is a common sight to find the buffalo working contentedly and with ease in knee-deep, muddy water in rice fields. Although possessing a massive body frame and large hooves, buffaloes are quite nimble-footed and work with ease in very small plots without damaging the low mud walls, called 'bunds', forming partitions between the plots. Apart from ploughing and harrowing, buffaloes are used for many other types of work such as threshing, drawing water for irrigation, expressing oil from oilseeds or juice from sugar cane in sugar mills, puddling clay for preparing bricks, logging and haulage of loads on sledges or carts. In Pakistan and Sabah, buffaloes are widely used as pack animals and for riding. Buffaloes play a role even in races and games in Indonesia and Sabah.

In northern India buffaloes have replaced cattle bullocks for haulage of sugar cane from the fields to the factory. Buffalo introduction into Latin American countries was motivated by the idea of using them to haul sugar cane to the factories.

Although the majority of working animals are males, female buffaloes, dry or with a poor milk yield, are also sometimes put to work. This practice is not uncommon in Egypt, parts of Indonesia and the Philippines. For drawing heavy loads buffaloes are hitched singly or in pairs to crudely built wooden carts. They are used extensively for this purpose in India, Pakistan, Indonesia and other countries, particularly in and around urban areas. On good roads, it is not unusual to find a pair of buffaloes drawing a load of about 2 t at a slow pace of 3.2 km an hour. As buffaloes are incapable of working for long on hot days, when they are exposed to direct sunlight during the hot summer they need to be put to work at night or in the early morning. As work animals, male buffaloes are used both castrated or uncastrated. The practice varies from country to country, following local beliefs and customs. In India and Pakistan castration is not the usual practice and uncastrated animals seldom, if ever, become intractable. Castration, if carried out, is done at a late age, as early castration is believed to produce a poor working animal. Docility and mild manner make the buffalo so easy to manage at work that in many instances no restrictive controls are necessary. Whips or chains are seldom used to drive the animal.

For working on hard ground, hooves of buffaloes need protection against excessive wear by shoeing. Thin iron plates are used in India and Pakistan. Shoes made of straw and 'trompas'shoes made from old motor tyresare used for this purpose in Taiwan and East Java respectively (Cockrill, 1968).

Milk Production

As a dairy animal the buffalo is found at its best in India, Pakistan, Egypt and Iraq. Even though milking buffaloes constitute only about 40% of the total milking bovine stock in India, it is they and not the cow that form the principal dairy animal, contributing 56% of total milk. The buffalo in India yields on an average 1041 kg of milk per year as compared with an average yield of only 631 kg by cattle. Milk yield varies widely, depending on the breed and husbandry practices. Daily milk yield of a lactating buffalo in India and Pakistan may be as low as 2.5 kg in a poor village animal and as high as 20 kg or more for a good buffalo on a well-managed farmstead. The average yield from five selected herds in India was found to be a little over 2055 kg per lactation. In another high-yielding buffalo herd 2.7% of the lactating buffaloes gave a yield exceeding 3630 kg of milk per lactation. According to Rife (1959) four well-managed farms in Pakistan showed an average yield of over 1860 kg per lactation (range 1507 to 2128 kg). In Egypt the average milk yield is lower. Buffaloes maintained on government farms and research stations show an average milk yield of 1814 kg or less per lactation (range 226 to 3856 kg) (Ragab *et al*., 1954). The Marsh Arabs of southern Iraq rear their buffaloes with great care but under conditions unendurable to most livestock breeders. Even under these circumstances, an average yield of 6 kg of milk for more than 200 days is not unusual. In the author's opinion these buffaloes are potential high yielders and their performance can match those of good milk breed buffaloes in other countries.

Attention has not been given so far to developing milk characteristics in swamp buffaloes, which have an incredible capacity for work. Yet in the Philippines, where working swamp buffalo are milked, a yield of 23 kg a day is common. Caucasian buffaloes, a new breed developed in Russia, yield on an average 1352 kg of milk containing 8.1% fat in 300 days (Agabeili *et al*., 1971).

The average first lactation milk yield in Murrah buffaloes varies between 1540 and 1868 kg (Bhalaru & Dhillon, 1978; Sreedharan & Nagarcenkar, 1978; Patro and Bhat, 1979a; Reddy, 1980); in Nili-Ravi it is 1707 kg (Reddy & Taneja, 1984). Alim (1967) reported the lactation milk yield of 1771 kg and Fahmy *et al*. (1975) reported 13602267 kg for Egyptian buffaloes. The first lactation averages for Bhadawari (1165 kg), Nagpuri (926 kg) and Surti (1364 kg) are much lower.

Average milk yield in Nili-Ravi buffaloes in Pakistan varies between 1969 and 2731 kg (Ashfaq & Mason, 1954; Cady *et al*., 1983) while the average milk yield in the Kundi breed is 1781 kg (Wahid, 1976). Cady *et al*. (1983) observed that 1.2% of all buffaloes at the government farms produced more than 4000 kg milk in a lactation.

Arora *et al*. (1962) reported that milk yield increased from first (1733.6 kg) to sixth (2563.6 kg) lactation in Murrah. Patro & Bhat (1979a) observed a steady increase from first lactation onwards with a peak in the fourth lactation. The milk yield up to the ninth lactation was maintained close to the peak lactation suggesting that buffaloes could be maintained in the herd up to the ninth lactation (16 years of age) with reasonable economic returns. They suggested that stage of lactational maturity corresponded with the development and increased functioning of active secretory tissue of the udder which was attained around the fourth lactation. As a species, lactational maturity in buffaloes was attained between the fourth and sixth lactation.

Significant effects of farms and years/periods on milk yield have been reported (Kumar & Bhat, 1978; Patro & Bhat, 1979a; Reddy, 1980). Patro & Bhat (1979a) observed the farm differences to be significant for all the six lactations, while Polihronov *et al*. (1967) reported it to be non-significant for Murrah and for Bulgarian buffaloes.

Bhat & Patro (1978) examined the effects of age and weight at calving, preceding dry period and preceding service period on milk yield adjusted for effects of farm, period and season of calving. Age at calving had positive and significant effect on milk yield up to the third lactation, while weight at calving and preceding service period had an effect up to the fifth lactation. Longer preceding dry periods were not favourable for higher milk yield. The age and weight at calving preceding service and dry period and lactation length together explained 34% of the total variability in milk yield. These factors, without lactation length, explained only 9.7% of variability. These results suggest that lactation length was a major source of variation in milk yield.

Most of the heritability estimates for first lactation milk yield in Murrah buffaloes ranges between 0.08 ± 0.04 and 0.19 ± 0.08. The heritability estimate for Nili-Ravi was 0.28 ± 0.20 (Bhullar, 1974).

Significant phenotypic correlations between first lactation milk yield and first lactation length (0.42 to 0.65) have been reported by Johari & Bhat (1979b), Patro & Bhat (1979b) and Reddy (1980). The genetic correlation between first lactation yield and first lactation length was 0.46 ± 0.24 (Johari & Bhat, 1979a) while that between milk yield and lactation length over the first six lactations were not significantly different from zero (Patro & Bhat, 1979b).

Lactation Length

The first lactation length in Murrah and Nili-Ravi is around 300 days (Basu & Ghai, 1978; Reddy, 1980; Sharma & Basu, 1984; El-Arian, 1986). However, higher averages of 321, 323 and 349 days in Murrah buffaloes have also been reported by Singh & Basu (1988). In Bhadawari, Nagpuri and Surti it is between 276 and 295 days (Singh & Desai, 1962; Belorkar *et al*., 1977). Lactation length is high (359426 days) in Surti buffaloes (Basavaiah *et al*., 1983; Rao *et al*., 1985). Alim (1967) reported the first lactation length as 325 days in Egyptian buffaloes.

Significant effects of farms on lactation length have been reported by Kanaujia *et al*. (1975) and Patro & Bhat (1979a), while Reddy (1980) reported it to be non-significant. Significant differences between months/seasons for lactation length have been reported by Patro & Bhat (1979a) and Jain & Taneja (1982) for Murrah; Polihronov *et al*. (1967) for Bulgarian; and Roy Choudhury *et al*. (1971) for Italian buffaloes. These authors observed that off-season calvers (DecemberJune) had longer lactation length.

Patro & Bhat (1979b) reported heritability estimate of 0.11 ± 0.05 for first lactation length. Higher heritability estimates of 0.28 ± 0.11 (Sharma, 1983) and 0.31 ± 0.06 (Singh & Tiwana, 1983) for lactation length have also been reported. The estimates for subsequent lactation lengths were lower than for the first.

Negative phenotypic correlations between lactation length and dry period have been reported by Basu & Ghai (1978). Reddy (1980) and Jain (1982) reported it to be low. The phenotypic correlations between lactation length and calving interval and between lactation length and service period were, in general, high0.510.76 (Basu & Ghai, 1978; Reddy, 1980; Jain, 1982)suggesting that longer lactation period would increase calving interval. The high correlation between first lactation length and calving interval is expected because lactation length is part of the calving interval and a major cause of variation in it. Similarly, service period is a cause of variation in lactation length. These correlation values suggest that an increase in service period will lead to an increase in lactation length and calving interval which is not a desirable breeding objective.

Measures of Efficiency of Milk Production

The first lactation milk yield is the most commonly used selection criterion in dairy animals. The economic merit of dairy animals, however, is also influenced by many other characters like age and weight at first calving, lactation length and calving interval. Although selection index procedure is the most efficient method of combining many traits into a single measure of net merit, it needs the facilities of a performance recording system, a computer and cannot be easily used under field conditions. It is, therefore, essential to develop a simple measure of milk production efficiency which takes into account variation caused by factors like lactation length, calving interval and age at first calving, and has high genetic correlation with milk yield. Some measures of milk production efficiency developed are: milk yield per day of age at calving, milk yield per kilogram of weight at first calving, milk yield per day of lactation length and milk yield per day of calving interval.

The average milk yield per day of lactation length ranged from 4.06 to 6.62 kg (Ram *et al*., 1976) in Murrah buffaloes. Amble *et al*. (1970) reported it to be 5.50 ± 0.34 and 6.10 ± 0.34 in Nili-Ravi buffaloes at two farms. El-Sawaj *et al*. (1964) reported an average yield per day of first lactation length as 4.84 kg in Egyptian buffaloes.

The milk yield per day of calving interval ranged between 3.02 and 4.00 kg (Amble *et al*., 1970; Singh, 1976; Rao *et al*., 1976; Bhalaru & Dhillon, 1981; Bhat *et al*., 1982) in Murrah buffaloes. It was 3.70 ± 0.24 and 4.00 ± 0.20 kg in Nili-Ravi buffaloes at two farms (Amble *et al*., 1970).

Bhalaru & Dhillon (1978), Reddy (1980) and Bhat *et al*. (1982) estimated genetic parameters for some measures of milk production efficiency and compared these with heritability estimates for milk yield. Most of the estimates reported by Reddy (1980) and Bhat *et al*. (1982) for milk production efficiency parameters were low and many of these were not different from zero. The trend, however, was that the heritability estimates for milk yield per day of lactation length and calving interval were higher than those for first lactation yield.

Bhalaru & Dhillon (1981) observed that heritability of milk yield per day of first lactation length (0.29 ± 0.10) was higher than that of first lactation yield (0.19 ± 0.09). The genetic correlation between these two traits was 0.90 ± 0.05. The coefficient of variation, however, for milk yield per day of lactation length was low (22%) as compared to first lactation yield (27%). In view of the higher heritability of milk yield per day of first lactation length and the higher genetic relationship with milk yield, selection on the basis of this trait would result in higher genetic improvement than expected from selection for milk yield.

Bhalaru & Dhillon (1981) evaluated the usefulness of some measures of efficiency of milk production in buffaloes as selection criteria as compared to selection based on either first lactation yield or an index incorporating age at first calving, first lactation yield and first calving interval. The results of accuracy of different criteria of selection revealed that a selection index was the most accurate criterion of selection (r = 0.603). Out of different measures of efficiency of milk production, the milk yield per day of age at second calving had the highest correlation (r = 0.462) with net merit, followed by milk yield per day of first lactation length (r = 0.415) and first lactation milk yield (r = 0.294).

Herdlife.

The average productive life (sum of the first three or four calving intervals) in Murrah buffaloes is 1378 and 1884 days (Sharma & Singh, 1975; Tomar & Basu, 1981; Kalsi & Dhillon, 1982). Sharma & Basu (1986a) reported the herdlife in Murrah buffaloes to be 1947.04 ± 72.47 days. Herdlife is the difference between the date of first and last calvings. Dutt *et al*. (1965) estimated the productive life (date of birth to date of disposal) as 83.29 ± 5.22 months and longevity (date of first calving to date of culling) as 126.87 ± 5.33 months for Murrah buffaloes. Kalsi & Dhillon (1982) reported the productive life (sum of first four calving intervals) for large-size dairy buffaloes of unspecified breed to be 1359 ± 83.40 days. It appears that most buffaloes complete about six lactations in their life time in about 7 years.

Lactation Curve

It is well known that the milk yield after parturition in an animal rises to the maximum in the first few weeks, tends to remain around this level for a short period and then gradually declines until secretion finally stops. This pattern of milk secretion can be represented mathematically with respect to time and is commonly known as the lactation curve.

Various mathematical models have been developed to explain both the ascending and descending phases of the lactation curve. The exponential function (Brody *et al*., 1923) *Yt = Ae-kt* which described only the rate of decline of milk secretion was the first to be used. Subsequently, the parabolic exponential function (Sikka, 1950) $Yt = Ae^{bt+ct^2}$, gamma-type (Wood, 1967) *Yt = At = Atbe-ct*, and inverse polynomial (Nelder, 1966) *Yt = t(A + bt + ct*2)-1 were developed to forecast the milk yield at any stage of lactation.

Dave (1971) studied the lactation curve in two herds of buffaloes. The animals were divided into three groups based on the lactational duration: (1) below 250 days, (2) above 250 days and less than 360 days, and (3) above 360 days. A polynomial of second degree was fitted to the lactation curve except in one case of short lactation (below 250 days). The milk yield generally showed linear trend, and 7596% of the total variation was accounted for by linear regression coefficient of yield on time. The linear trend showed an increase in tendency from short lactation to long lactation period. In the short lactation period, yield increased with the passage of time but showed downward trend earlier. In the longer lactation period, the milk yield showed continuous increasing tendency and remained constant thereafter.

Kumar & Bhat (1979) fitted exponential, parabolic exponential, gamma type and inverse polynomial functions on average lactation records of six lactations. The *r*2 values for these functions showed that the gamma-type function gave the best possible fit followed by inverse polynomial, parabolic exponential and exponential. These functions explained variability up to 99.099.3, 98.098.5, 94.596.5 and 75.379.6%, respectively, by iterative procedure. It was suggested that the gamma-type function followed by inverse polynomial should be preferred over others for describing the lactation curve in Indian buffaloes.

Lifetime Production

Chaudhary & Shaw (1965) reported average production life to be 72.0 in Nili-Ravi buffaloes of Pakistan and Asker *et al*. (1971) reported 76.8 months in Egyptian buffaloes. Dutt *et al*. (1965) recorded in Murrah buffaloes yield up to the first three lactations as 3308 ± 116 kg while Iqbaluddin *et al*. (1970) recorded it to be 4848 ± 112 kg and 4475 ± 120 kg, respectively, at two farms in Murrah buffaloes. Patro and Bhat (1979b) reported the milk yield in the first three lactations in Indian buffaloes to be 5131 kg. The analysis of data in their study revealed that by the end of the fourth lactation more than 50% of the buffaloes left the herd and only less than 1% completed ten lactations.

Singh and Tomar (1981) reported economic levels of various early economic traits on the basis of lifetime milk production and herdlife (age at disposal). It was found that age at first calving (below 42 months), higher first lactation production (over 2000 kg) and lower first calving interval (not more than 15 months) would result in significant increase of herdlife and lifetime milk production.

Sharma & Basu (1986b) fitted polynomial regression up to the third degree using lifetime records of 804 Murrah-type buffaloes to determine optimum levels of various economic traits. Regression curves of lifetime traits on age at first calving showed a linear progression and continuously decreased with increase in age at first calving, indicating higher lifetime milk production and longer stability for early calvers. They observed no lower limit to age at first calving, perhaps because the optimum age of calving was outside the range observed in their study.

From the reports reviewed, it may be concluded that lower age at first calving, preferably below 42 months and higher first lactation milk yield, preferably over 1800 kg, were desirable for lifetime production.

Milk Composition

Buffalo milk is much richer than cows' milk with respect to butter-fat content that may be as high as 15% under good feeding and management. The average fat content is higher than that of cows' milk, possibly a little over 7% except in Egyptain buffaloes (6.6%; Alim, 1978). The solids-not-fat (SNF) content is around 910.5% and is generally slightly higher than that of cows' milk (Table 8.15). Protein, lactose and mineral together constituted 9.6% in Indian buffalo (Pal *et al*., 1971), whereas almost similar contribution by these factors was in Egyptain buffaloes (Alim, 1978). Buffalo milk is used for preparing the same products as those made from cows' milk such as yoghurt, sweets, ice-cream and various types of cheese. Soft cheese made from buffalo milk in the Philippines and Iraq are delicacies, and mozzarella (the Italian pizza cheese made from buffalo milk in southern Italy) is a product of world fame and a gourmet's delight. In India, good-quality processed cheese is manufactured from buffalo milk. Ice-cream made from buffalo milk, with its rich cream, tastes better than any other available in the market.

A clarified form of butter called *ghee* in India and Pakistan or *semu* in the Arab countries is prepared from buffalo milk. This is extensively used as a cooking medium by millions of people in the Indo-Pakistan sub-continent and in the Arab world and is greatly relished. Buffalo milk, butter and ghee are white in colour due to the absence of carotene, but the products are rich in Vitamin A.

Singh *et al*. (1979) observed that lactational fat percentage was affected significantly by year and season while parity of calving did not influence the fat percentage. However, year, season and parity of calving affected the lactational SNF percentage significantly. The monthly fat percentage was significantly influenced by stage of lactation and parity while the monthly SNF percentage was not affected either by stage of lactation or parity of calving. The fat percentage showed a continuous increase from the first to the tenth month. The influence of season of calving on fat percentage is well recognized. Both the fat and SNF percentage were maximum among autumn calvers and minimum among rainy season calvers (Singh *et al*., 1979). However, Ragab *et al*. (1958) reported higher fat percentage in summer calvers than in winter calvers in

Table 8.15 Composition of buffalo and cows' milk.

Species	Fat (%)	Protein (%)	Lactose (%)	Total solids (%)
Buffalo	7.64	4.36	4.83	17.96
European cow (*Bos taurus*)	3.90	3.47	4.75	12.82
Zebu cow (*Bos indicus*)	4.97	3.18	4.59	13.45

Egyptian buffaloes. In contrast SNF percentage was higher in winter than the summer calvers. No explanation for this has been given.

Pal *et al*. (1971) reported that percentage protein had a high heritability (0.74) while percentage ash (0.29), percentage total solids (0.35) and percentage SNF (0.39) were moderately heritable. The repeatability estimates for fat (0.71), ash (0.68), total solids (0.72) and SNF percentage (0.68) were high, while those for protein (0.42), lactose (0.36) and casein percentage (0.57) were moderate. However Singh *et al*. (1979) estimated heritability for percentage fat and SNF as 0.41 ± 0.28 and 0.26 ± 0.23 respectively. The repeatability estimates for percentage monthly fat in their study ranged from 0.20 to 0.49 and of percentage SNF from 0.19 to 0.37.

Pal *et al*. (1971) estimated the genetic correlations among milk constituents to be positive (0.28 to 0.97%). The highest correlation values were observed between total solids and other constituents. Singh *et al*. (1979) reported positive correlation between fat and SNF percentage (r = 0.57). However, the correlations between milk yield and constituent percentage were negative, and ranged between 0.26 and 0.77. These results suggest that selection for milk yield would lower milk constituent percentage, and vice versa. Although the increase in milk yield will decrease the milk constituent percentage, total fat, protein and SNF yield would increase as all yields are positively correlated with milk yield (Pal *et al*., 1971).

Selection Indices

In various farm animal species, selection indices are used to estimate the breeding value of future breeding stock. A selection index estimates the value of an individual for an aggregate genotype, whereas the latter in most applications is expressed in financial terms and is a linear combination of additive genetic merit for component traits weighted by their respective economic weights. Selection indices have been constructed for buffaloes by Tomar & Desai (1969), Kanaujia *et al*. (1974), Bhalaru & Dhillon (1978), Johari & Bhat (1978) and Gokhale & Nagarcenkar (1980).

Johari & Bhat (1978) constructed indices involving traits of growth, reproduction and production. Comparative study of the relative efficiency of these indices indicated that a selection index incorporating birth weight, weight at 6 months, weight at 1 year, weight at first calving, first lactation milk yield and lactation length had the highest relative efficiency and was slightly superior to an index based on all nine traits. It was recommended that sequential selection would be more useful for genetic improvement. At 1 year of age, the heifers should be selected using an index which incorporated body weight at birth, 6 months and 1 year. When body weight at first calving and age at first calving become available, the index incorporating body weights at 6 months, 1 year and first calving, and age at first calving could be used. At the completion of first lactation record, the index which incorporated body weights at 6 months, 1 year and first calving, age at first calving, first lactation milk yield and lactation length could be used; it was as efficient as the best index. The authors suggested that reproductive traits should be improved through efficient feeding, management and improved sexual and health control operations.

Response to Selection

Alim (1953) estimated the genetic gain for milk yield through dams of buffalo cows and bulls as 5.7 and 13.4 kg, respectively, in a herd of Egyptian buffaloes. The total generation length through four paths was 27 years and the annual gain in milk yield was 0.71 kg (0.04% of the herd average). Asker *et al*. (1955) did not observe any effect of selection for age at first calving or calving interval in Egyptian buffaloes over a period of 20 years. Genetic improvement in milk yield from selection of dams of heifers was 60.3 kg per generation. The annual genetic gain in milk yield was 8.1 kg which was 0.8% of the herd average.

Agarwala (1956) estimated the annual genetic gain in butterfat yield in a herd at Allahabad as 0.10 kg which was about 0.1% of the average first lactation butterfat yield of 95.9 kg. Reddy & Taneja (1982) estimated the genetic gain in milk yield in a Murrah herd at Military Farm, Jabalpur. The estimates of genetic superiority through four paths, namely sire to daughter, sire to son, dam to daughter and dam to son were 7.92, 4.91, 80.45 and 438.94 kg, respectively, which were equal to 1.49, 0.92, 15.12 and 82.47% of the total. In this study, the genetic contribution from dam to daughter path was much higher than the sire to daughter path. In selection of bulls also, maximum emphasis on dams' performance was indicated by the highest genetic superiority through dam to son path (82.47 percent). Thus in selecting both cows and bulls, the emphasis was mostly on their dams' performance. This was expected in the absence of progeny testing. However to maximize the rate of genetic gain, a combination of selection of outstanding bull mothers and progeny testing of bulls should be practised. The annual genetic gain in 300-day first lactation milk yield was 15.88 kg, equal to 0.99% of the herd average of 1611.26 kg. Singh (1983) estimated the annual genetic gains for milk yield using progeny testing, half-sib testing, pedigree and individual selection for population sizes of 400, 1600 and 10 000 buffaloes. An increase in genetic gain with increase in population size was noted in progeny testing and half-sib methods. The annual genetic gains for a herd size of 10 000 were 1.04, 1.00, 0.07 and 0.06% of the herd average respectively. Gain from half-sib testing was almost equal to progeny testing because of the smaller generation interval in half-sib testing. Expected gains from pedigree and individual selections were negligible.

Most of the studies reviewed above indicate that selection of both bulls and heifers should be done on the basis of the dam's performance. For making an improvement in milk yield, it is essential that outstanding bull mothers are selected and progeny testing of young bulls is taken up to maximize the rate of genetic gain. Considering a heritability estimate of 0.15 for milk yield in 300 days and different selection intensities (culling at 10, 20 and 30% of herd), the improvement (DG) per year will be between 3.76 and 9.60 kg (Table 8.16).

Ashfaq (1961) reported the results of a study of progeny testing of the buffalo bulls maintained at the Government Buffalo Breeding

Table 8.16 Rate of genetic improvement in milk yield. (*Source*: Bhat, 1983.)

% culled	*i*	*h*2	s*p*	D*G* per generation (kg)	D*G* per year (kg)
10	0.195	0.15	900	26.33	3.76
20	0.340	0.15	900	45.90	6.56
30	0.498	0.15	900	67.23	9.60

Farm, Bahadarnagar in Pakistan during 194751. The analysis showed that progeny testing was feasible. A comprehensive study was conducted to explore the extent of genetic and environmental sources of variation in the productive and reproductive traits of a purebred herd of Nili-Ravi buffalo (Khan, 1986). The effectiveness of selection and inbreeding in altering the milk producing ability of the animals over a period of 44 years was also studied (Khan & Ahmed, 1991).

The data showed that the average estimated genetic superiority of the dams of she-buffalo (*I*CC) was 11.34 kg or 0.598% of the herd average per generation; the average estimated genetic superiority of dams of bulls (*I*CB) was 84.20 kg of milk or 4.44% of the herd average per generation. Since progeny testing was not practised in this herd, the other two paths of genetic superiority, namely *I*BB and *I*BC, amounted to zero. The pooled genetic superiority was 95.55 kg of milk or 5.04% of the herd average for a generation interval of 7.38 years. The genetic improvement per year, thus amounted to 3.278 kg of milk or 0.171% of the average first lactation milk yield (1869 ± 38.8 kg and heritability, 0.137 ± 0.083). Out of the genetic improvement in milk yield, 88% was due to the selection of the dams of the sire (*I*CB).

The estimate of annual genetic improvement in milk yield through selection was not only markedly low but was also much less than 1 % of the mean suggested by Rendel & Robertson (1950) as the maximum rate of genetic improvement without progeny testing. Thus it may be concluded that:

(1) Although selection remained ineffective to bring about the desired changes over a long period of 44 years, there was scope for six-fold improvement in production through direct selection.

(2) Selection of buffaloes to produce heifers (*I*CC) was ineffective because the selection of dams to produce heifers and bulls was primarily done on the basis of type and conformation with little attention to milk yield since 1936. It was obvious that these characters had little or no correlation with traits of economic importance.

(3) The logical consequence of the above finding is that a progeny testing programme for buffaloes needs to be initiated. This was obvious from the fact that 12% genetic gain was from the selection of dams of cows (*I*CC) and 88% was obtained through the selection of dams of bulls (*I*CB). This conclusion is further substantiated by the findings of Cady *et al*. (1983) who reported that at government livestock farms, 1% of all buffaloes produced more than 4000 kg milk and this proportion of high-yielding buffaloes gave good opportunity for the selection of dams to produce bulls (*I*CB).

Ahmed *et al*. (1992) analysed data of 1457 Nili-Ravi buffaloes to estimate age-specific probabilities of cows culled for low milk yield, reproductive failures, poor health and old age. Reproductive failure was identified as the principal reason for the culling of buffalo cows. Reproduction and health accounted for two-thirds of all culling, leaving a relatively narrow margin for culling based on low milk yield.

Progeny Testing of Bulls

It was with this background that the progeny testing programme in Pakistan was started at the Livestock Production Research Institute, Bahadarnagar, Okara in 1979. It was a station-testing programme; two batches of bulls with four bulls in each batch were put to test mating during 197980 and 198182, respectively, allowing random herd mates to each bull. In batch I, four bulls were put on the test mating herd in 1979 and 4050 conceptions from each bull were randomly obtained. The daughters of these bulls who attained sexual maturity were bred accordingly. The bulls were ranked according to the method described by Jain & Malhotra (1971). These bulls were recommended as sires for the production of future candidate bulls after preserving sufficient doses of their semen. By 1982, four bulls which were the sons or grandsons of proven sires out of top-class bull mothers were put on test mating in the test herd, i.e. buffaloes other than elite cows. Out of 94 daughters, 28 completed their first lactation while the others were culled for various reasons. Since the progeny testing programme was confined only to the Livestock Production Research Institute, Bahadarnagar, Okara, where a small number of buffaloes were present, accuracy was expected to be low and selection was not large enough to allow significant genetic progress. Hence, field recording of farmers' herds, as an adjunct to institutional programme was initiated. A co-ordinated field progeny testing project was started in 1984. The new programme was extended to three buffalo populations, that is buffaloes at the government farms, buffaloes with progressive farmers and buffaloes from the selected village population.

Asghar (1987) highlighted the important features of this programme. About 800 breeding buffaloes at different livestock experiment stations and military farms and 4000 buffaloes kept by the farmers in the home tract of the Nili-Ravi buffalo were registered. The criterion for registration was more than 10 litres of milk daily during their peak period. The sons from elite buffaloes and sires assessed for breeding value by Cady *et al*. (1983) were taken as the base for progeny testing programme. The buffaloes from these populations were inseminated with the semen from the proven sires or the best available sires to produce candidate bull calves. The topmost 3540 bulls were put on test mating every year in all buffalo populations until 80100 conceptions were obtained from each bull. Such bulls were ranked by contemporary comparison. Mean lactation yield of 1770 buffaloes at the government and military farms was 1873 ± 14 kg. The top 12.8% of these buffaloes were selected as bull mothers and the average lactation yield of these elite buffaloes was 2760 ± 13 kg. The average milk yield of 3177 registered buffaloes from the field was 2074 ± 10 kg, and 9.9% of these buffaloes having an average milk yield of 3215 ± 8 kg were selected as bull mothers. In 198384, 16 bulls were put on test mating on all the buffalo populations registered under the project. These bulls attained a body weight of 420570 kg at the age of 24 months. The fertility in these bulls was 52.7%. At the end of this phase of the project, a total of 185 contemporary daughters had completed at least one lactation each. The analysis of the data revealed a non-significant difference in the 305-day milk yield of buffaloes kept at the government farms and at the private farms. Hence, the two sets of data were pooled and the bulls were ranked accordingly.

The differences among the bulls were significant ($P < 0.05$) but the top three bulls of the four tested (B-62 PD 210, B-63 PD 284 and B-65 PD 175) did not differ from each other. Until now, seven batches of 124 young candidate bulls have completed test mating and the data are being analysed.

Co-ordinated Research Project on Buffalo Improvement

An All-India Co-ordinated Research Project on Buffalo Improvement was initiated by the Indian Council of Agricultural Research in 197071. Two centres each for Murrah and Surti breeds were established at different locations in the country. The detailed objectives and the breeding programme of the project have been described by Nagarcenkar (1978). The project envisaged evaluating buffalo bulls both under farm and field conditions. A number of bulls of the two breeds with 20% superiority above their contemporary average have been identified and these are being used for improvement of the herd and in elite matings for production of young bulls for testing. Elite dams with more than 2000 kg milk for the Murrah breed and 1200 kg for the Surti breed have been identified and used in mating with the tested bulls. So far 40 bulls of the Murrah breed have been progeny tested with daughters' performance of 2000 kg/305 days to 2700 kg/305 days for various proven bulls. The frozen semen of these bulls is being used for improvement of buffaloes in the breeding tract.

Meat Production

Buffalo meat is usually eaten in all Asian countries where buffaloes exist. It generally commands a ready sale, though sometimes it is regarded as inferior to beef and is sold at a lower price. Buffalo meat in most of the countries is produced and handled under very unsatisfactory conditions and mostly old buffaloes, unfit for economic milk production or work, are slaughtered. The dressing percentage in such cases is low, being about 4347%. Even so, such buffalo meat is considered a delicacy by people used to eating it. The meat of the buffalo is used with advantage for the preparation of hamburgers, meat rolls and sausages. It also makes good biltong and tasty soup. Like the milk and butterfat, the body fat of the buffalo is white on account of an absence of carotene. According to Bhat (1994), in India 10.52 million buffaloes are slaughtered to produce 2.62 million t of buffalo meat with an average carcase weight of 146 kg. Of the total buffaloes, 89% were slaughtered in Asia to produce 1.60 million t of meat. Pakistan and China alone contributed close to 79 000 t of meat.

Certain European countries, most notably Italy, Bulgaria, the former Czechoslovakia and the former USSR have done valuable research in buffalo meat production. Buffaloes in these countries are fed for slaughter at 1620 months when they weigh 350400 kg. The dressed carcase percentage is 5160. Meat quality is good and flavour is indistinguishable from that of beef (Alim, 1967; Dzafraov, 1968). In Trinidad, Indian breeds like Murrah, Surti, Jaffarabadi, Nili-Ravi and Bhadawari have been crossed with nondescript buffaloes; crossbred progeny being raised for beef production (Rastogi *et al*., 1978). An average group weight of 476 kg at 2 years of age was attained in these crosses giving a daily weight gain of 512 g. Higher rates of gain between 900 and 1150 g per day have been achieved in China and the former USSR. The carcase dressed out between 52 and 62%. Buffalo meat was as palatable as beef sold in the market (Dzafraov, 1968; Pei-Chien, 1978).

In buffalo meat the fibres are not interspersed with fat and hence the tenderness produced by 'marbling' is absent. This, however, does not appear to be a characteristic of meat from this species. It is more likely that the coarseness observed in buffalo meat is not due to any intrinsic defect but to the fact that the animals are usually old and in poor condition when slaughtered. The dressed carcase of the buffalo generally represents 4547% of the live weight of the animal. In the former Yugoslavia, Bulgaria and Italy where rearing of buffaloes for meat is common, a dressing percentage of 51 is not unusual. Caucasian buffaloes yield carcases with a dressing percentage varying from 48 to 53. The protein content of the meat ranges between 19.2 and 22.4% and that of the fat between 11.4 and 22.2% (Agabeili *et at*., 1971).

In some markets such as Hong Kong buffalo meat constitutes more than half of all the beef sold.

In the early 1990s studies were conducted on the meat-production characteristics of weaned male Murrah buffalo calves at the Indian Veterinary Research Institute (IVRI) in India. Groups of 9-month-old calves weighing 75 kg were divided into two groups, one lot being on *ad libitum* high-grain ration and the other on *ad libitum* roughage-type, leguminous hay and wheat straw ration. On attainment of 300 kg body weight the animals were slaughtered for evaluation of carcase quality. Animals fed the high-grain ration demonstrated growth rates of 0.5550.628 kg per day, and attained a slaughter weight of 300 kg at 1618 months of age, whereas those on the roughage-type ration gained at the rate of 0.4100.450 kg per day and reached the same slaughter weight in 2022 months. The dressing percentage of the high-grain-fed animals ranged from 56.8 to 59.6 (mean 57.4), while that of animals fed roughage-type rations varied from 50.8 to 53.5 (mean 50.9). The lean: fat: bone ratios in the grain-fed and roughage-fed groups were 55:26:28 and 59:19:21 respectively. If the buffalo is properly managed and fed as a meat-producing animal and slaughtered at 1620 months of age it can produce meat that would be comparable with beef obtained from cattle, both in quality and in quantity.

Krishnan & Nagarcenkar (1979) observed average daily gain in body weight in buffalo calves as 474 g from birth to slaughter and 513 g from 6 months to slaughter under conventional concentrate feeding. The corresponding averages when calves were fed concentrate mixture containing urea and molasses were 421 and 386 g respectively. The differences in average daily gain under the two feeding regimes were significant. For meat studies, the calves were slaughtered in weight groups of 140, 180 and 200 kg. The dressing percentage was highest (58.7%) under conventional concentrate feeding in the 180 kg weight group, while it was lowest (53.5%) under experimental concentrate feeding in the 140 kg weight group.

In China, Liu (1978) made a comparison of fattening efficiency between triple crossbred (1/2 Nili-Ravi × 1/4 Murrah × 1/4 local) buffaloes and 1/2 Santa Gertrudis grades under the same feeding conditions, both slaughtered at 18 months of age. The dressing percentages were 53.0 and 59.9, muscle percentages 43.2 and 42.1 and bone ratios 1:4.5 and 1:4.4 respectively. The buffalo meat was also as palatable as beef. In another feeding experiment, triple-cross buffalo steers maintained on elephant grass for 100 days gave a daily weight gain of 0.8 kg and the animals consumed 67.3 kg of elephant grass for each kilogram increase in body weight. The animals when slaughtered at 24 months of age gave a dressing percentage of 53.6 with a muscle percentage of 43.0.

A report on the comparative palatability of the cooked meat of water buffalo with that of the local crossbred Jamaica Red × Sahiwal steer and an imported carcase of European beef steer, revealed that meat from the water buffalo scored an average of 76.6 points versus 70.7 and 69.3 points, respectively, for the local and imported beef. The buffalo meat is considered to be of attractive colour, fresh and tasty. Buffalo veal is considered a delicacy. Calves are usually slaughtered for veal between 3 and 4 weeks of age and the dressed percentage is 59.66.

The water buffalo offers promise as a major source of meat, and the production of buffaloes solely for meat is now expanding. Because buffaloes have been used as draught animals for centuries, they have evolved with exceptional muscular development; some weigh 1000 kg or more. Until recently, however, little thought was given to using them exclusively for meat production. Most buffalo meat was generally, and still is, derived from old animals slaughtered at the end of their productive life. As a result, much of the buffalo meat sold is of poor quality. But when buffaloes are properly reared and fed, their meat is tender and palatable. Water buffaloes are exported for slaughter from India and Pakistan to Western Asia and from Thailand and Australia to Hong Kong. Demand for meat has been so great that Thailand's buffalo population has dropped from 7 million to 5.7 million head during the 1980s and 1990s, a period in which the human population has more than doubled.

All buffalo breeds, even the milking ones, produce heavy animals whose carcase characteristics are similar to those of cattle. Despite heavy hide and head, the amount of useful meat (dressing percentage) from buffaloes is almost the same as in cattle. In Mediterraneo-type buffalo in Brazil the dressing percentage is 55.5. Dressing percentage in swamp buffalo in Australia is 53.

Buffaloes are lean animals. Although a layer of subcutaneous fat covers the carcase, it is usually thinner than that on comparably fed cattle. Even animals that appear to be fat proved to be largely muscular. Research in Australia revealed that it is difficult to produce swamp buffaloes with more than 25% fat. An average choice-grade beef carcase may contain about 35% fat. This lower level of fat is sometimes seen even under feedlot conditions, although animals liberally fed with concentrated rations will eventually fatten. Castrated males have a reasonably even layer of subcutaneous fat.

In general, the buffalo carcase has rounder ribs, a higher proportion of muscle, and a lower proportion of bone and fat than has beef.

Buffalo meat and beef are basically similar. The muscle pH (5.4), shrinkage on chilling (2%), moisture (76.6%), protein (19%) and ash (1%) are all about the same in buffalo meat and beef. Buffalo fat, however, is always white and buffalo meat is darker than beef because of more pigmentation or less intramuscular fat (23% 'marbling', compared with the 34% in beef) and is low in cholesterol.

Taste-panel tests and tenderness measurements conducted by research teams in a number of countries have shown that the meat of water buffalo is as acceptable as that of cattle. Buffalo-steaks have been rated higher than beef-steaks in some taste tests in Australia, Malaysia, Venezuela and Trinadad.

There is some evidence that buffaloes may retain meat tenderness to a more advanced age than cattle because the connective tissue hardens at a later age or because the diameter of muscle fibres in the buffalo increases more slowly than in cattle. In one test the tenderness (measured by shearing force) of muscle samples from carcases of buffalo steers 1630 months old was the same as that from feedlot Angus, Hereford and Friesian steers 1218 months old. This gives farmers more flexibility in meeting fluctuating markets while still providing tender meat.

Buffalo hide makes excellent, thick, tough leather much valued for making shoe soles, belts and many other leather articles requiring this kind of material. Strips of buffalo hide softened with fat are woven to make very strong, attractive reins, lassoes or ropes. Very good and durable water buckets are made out of buffalo hide for lift irrigation purposes. Buffalo hide can be split with modern machinery to make thin strong sheets, which after processing and dyeing make as good a leather as that obtained from other animals.

Tasty 'buffalo chips' are made from buffalo hide in parts of Thailand, Nepal and Indonesia. The hide is cut into small strips, boiled in water for a long period and dried under the sun. The pieces are fried in deep fat to make crisp delicious chips. With adequate publicity it should be

possible to create an export market for buffalo chips.

The massive horns of the buffalo support a cottage industry. A wide range of useful as well as fancy and decorative horn articles are manufactured. The ingenuity, workmanship and beauty of many of these products are really fascinating. In Malaysia, a musical instrument known as *tetuag* is made out of buffalo horn (Cockrill, 1966).

The potentiality of buffaloes as a meat animal to meet the present and future requirements of a rapidly growing population in Asian countries deserves special attention, because of its capacity to convert economically coarse roughages and other cereal by-products into meat. Although buffaloes are being used for meat in these countries, there are no feeder/slaughter grades. There is an urgent need to produce these types.

Performance of Buffalo Crosses.

River × River Buffaloes

In Gujarat State, India, farmers have been breeding Surti buffalo cows with Murrah or Jaffarabadi bulls. Mehsana, a buffalo breed, is said to have been evolved from the crossing of Surti buffalo cows with Murrah bulls. A pilot study on crossing Surti females with Murrah bulls was undertaken at the National Dairy Research Instiute, Karnal, India (Table 8.17).

Murrah and Surti buffaloes were raised contemporarily. In crossbreds, a significant increase in milk yield and improvement in reproduction traits were observed (Basu & Sarma, 1982). In terms of efficiency of milk production (milk yield per day of calving interval), the crossbreds (3.4 kg) were even better than the Murrah (3.2 kg). In Bulgaria, crossing of native Bulgarian females with Murrah buffalo males imported from India was initiated in 1962. Murrahs were superior to Bulgarian buffaloes both for body weight and milk yield. The Murrah × Bulgarian crosses were close to Murrah for body weights at different ages (Table 8.18). The milk yield and total fat in the crossbreds were close to mid-parent value (Nagarcenkar, 1978).

Swamp × Swamp Buffaloes

There are no identified breeds of swamp buffaloes, although variations in coat colour, horn type and body weight are substantial. It is possible to crossbreed the swamp buffaloes with the river buffalo breeds. Research on crossbreeding of the swamp buffaloes with the riverine breeds, especially the Murrahs, has been conducted in different countries, e.g. China, Malaysia, the Philippines, Thailand and Vietnam. The number of chromosomes in the swamp buffalo is 48 ($2n$ = 24 pairs), while that in the Murrah breed is 50. The number of chromosomes in the F1 crossbred is 49 and, in spite of this change in chromosome numbers, both males and females are fertile. From a limited number of observations, the F2, F3 and F4 resulting from backcrosses to the Murrah also appear to be fertile.

Table 8.17 Performance of Murrah, Surti and their crosses. (*Source*: Basu & Sarma, 1982.)

Traits	Murrah	Murrah × Surti	Surti
Age at calving (months)	42.0	41.0	48.2
Milk yield, 305 days (kg)	1471.5	1415.6	1109.8
Lactation length (days)	324.1	321.2	294.9
Dry period (days)	157.9	106.7	165.1
Calving interval (days)	468.9	411.3	487.8
Efficiency of milk production (kg/day)	3.2	3.4	2.3

Table 8.18 Performance of Murrah, Bulgarian buffaloes and their crosses. (*Source*: Nagarcenkar, 1978.)

Traits	Type of buffalo		
	Murrah	Bulgarian	F1 Murrah × Bulgarian
Weight at birth (kg)	34.1 ± 0.4	31.9 ± 0.2	34.3 ± 0.2
Weight at 6 months (kg)	170.1 ± 1.7	132.3 ± 0.8	160.2 ± 2.7
Weight at 24 months (kg)	508.4 ± 6.8	432.8 ± 6.2	507.6 ± 5.7
300-day milk yield (kg)	1822.8 ± 75.7	1197.6 ± 13.2	1491.5 ± 18.7
300-day fat yield (kg)	145.2 ± 7.2	91.4 ± 1.1	113.9 ± 1.1
Lactation length (days)	306.2 ± 14.7	296.8 ± 4.9	288.0 ± 5.1
Dry period (days)	156.3 ± 19.7	151.1 ± 3.8	156.4 ± 5.2
Fat (%)	7.95	7.59	7.64

Growth

Buffalo crossbreds Philippine Carabao × Murrah or Phil-Murrah and Philippine Carabao × Nili-Ravi or Phil-Ravi were heavier than the Philippine Carabaos. The data from 322 Carabaos and crossbreds (102 Philippine Carabaos, 182 Phil-Murrah crossbreds and 38 Phil-Ravi crossbreds) were analysed. The variations in weights among the test animals were primarily due to breed of sire and locations. Regardless of sex, the crossbreds were heavier than the Carabaos at birth, and at 12, 24 and 36 months of age. It was also reported that the least-square mean weights of swamp × Murrah buffaloes were consistently heavier than those of swamp × swamp buffaloes at birth, and 6, 12, 18, 24, 36 and 48 months of age ($P < 0.05$).

Milk Production

Chantalakhana (1978) reported on the performance of imported Murrah, Nili-Ravi and their crosses with swamp buffaloes in Southeast Asian countries. Murrahs adapted well to the local environmental conditions, levels of feeding and management, and produced about two to three times more milk than the swamp buffalo cows. The crossbred buffaloes are superior in working ability to the swamp type and are nearly equal in milking ability to the Murrah. Age at first calving in the Murrah breed in these countries varies between 4 and 4.5 years. However, in crossbred buffaloes it is around 3.2 years. Murrah generally produced 3.55 kg of milk per day during their 200300 days of lactation.

Pei-Chien (1978) reported the performance of Murrah (imported from India), Nili-Ravi (from Pakistan) and their crossbreds with local swamp buffalos of China. Milk yield in the Murrah born and reared in China for an average lactation period of 213 days was 1382.9 kg. In general, the performance of Murrah grades was satisfactory. They were heavier and stronger than the local animals, especially in the hindquarters, good for working and produced more milk. Triple crosses produced using Nili-Ravi bulls on Murrah × local F1 cow, had an average body weight of over 200 kg at 6 months of age, the body weight being 300 and 450 kg at 1 and 2 years of age respectively. An average daily weight gain of 900 g was achieved in these triple crosses.

Liu *et al*. (1985) reported the performance characteristics of Chinese buffaloes, imported Murrah and Nili-Ravi buffaloes and their crosses. The Chinese buffaloes can be classified as large (³560 kg), medium (519559 kg) and small (<519 kg). They have the ability to thrive on coarse feed and live under rough management conditions. However, their milk and meat production is not high although the milk is rich in fat (7.811.3%). The average milk yield in Chinese buffaloes is 520 (210 days) to 751 kg (300 days).

The performance of exotic breeds, Murrah and Nili-Ravi, with respect to growth, production and reproduction compare well with those in their native homes and are higher than the averages reported for Chinese buffaloes. The average lactation yields for Murrah and Nili-Ravi are 1976 (272 days) and 2076 kg (275 days) with fat percentage of 6.7 and 7.2 respectively.

The average lactation yield of Murrah × local F1 progeny cows is 118.2% (271 days); and of the F2 is 1540.3 (291 days) with a fat percentage of 7.5. Use of Nili-Ravi bulls on 1/2 Murrah grade resulted in reduction in age at puberty (605 days) compared to 1/2 Murrah grade (669 days). Similarly, the post-partum oestrus period (71 days) and calving interval (382 days) in the triple crosses were lower than in the Murrah (94 and 455 days), the Nili-Ravi (128 and 466 days) and 1/2 Murrah grade (171 and 540 days). The average milk yield in these triple crosses was higher (2662 kg, 311 days) than those in the Murrah grades (1540 kg in F2 progeny), and approached the level of the Murrah and the Nili-Ravi. In general, growth, milk yield and confirmation of triple crosses appeared to be reasonably good; hence, the triple crosses are proposed to be used as the foundation stock for development of a new breed of milkmeat buffaloes in China.

In the Philippines the milk production of the Phil-Ravi F1 and the Phil-Murrah F1 is about 2.4 and 2.7 times more than the production of the Philippine Carabao (Table 8.19). The lactation length of the Philippine Carabao averages 200.8 days compared to the lactation of 348.5, 259.5 and 233.7 days for the Murrah, Phil-Murrah and Phil-Ravi respectively. The average daily milk yield of swamp buffaloes was 1.94 kg based on 10 lactation records; of the F1 of swamp × Murrah, 3.73 kg on 12 lactation records; of the F1 of swamp × Nili-Ravi, 4.3 kg on 60 lactation records; of the purebred Murrah, 6.60 kg on 81 lactation records; and of the purebred Nili-Ravi, 7.2 kg on 25 lactation records. The average lactation period was 235.9 days for swamp buffaloes; 276.9 days for swamp-Murrah F1; 270.8 days for swamp-Ravi F1; 237.1 days for purebred Murrah; and 261.0 days for purebred Nili-Ravi. The F1 crossbreds of swamp and riverine buffaloes on average produced about twice as much milk daily as that produced by swamp buffaloes.

In Sri Lanka, upgrading of local buffalo cows with Murrah and Surti from India resulted in a significant increase, of approximately 290%, in milk yield over the local buffaloes, which yielded 355 kg per lactation. Murrah were superior to Murrah grade only by 241 kg (16%) in milk production with no apparent difference in lactation length. Assuming a generation interval of 6 years and a turnover of five generations, one could expect an improvement of approximately 34 kg milk per year through the upgrading programme.

The crossbreds between swamp and Murrahs in Taiwan generally produce 3.55 kg of milk per day during 200300 days of lactation, with a peak yield of around 7 kg per day. The F1 crossbreds on average yield 3.4 kg per day (Table 8.20). However, in the Philippines only 1.6 kg of milk per day during 300 days is obtained from the crossbreds.

While these data indicate promising results from crossbreeding of swamp buffaloes with the riverine breeds, one of the most serious questions is how to proceed in the breeding programme without the risk of eliminating the local indigenous swamp buffaloes. It is also important to recognize that, under small-farm conditions in most Asian countries, there remain various socioeconomic aspects which need to be carefully

Table 8.19 Average milk yield (kg) and lactation length (days) of the Philippine Carabao, Murrah, Phil-Murrah F1 and Phil-Ravi F1. (*Source*: Shrestha & Parker, 1992.)

Parameters	Philippine Carabao (*n* = 21)	Murrah (*n* = 21)	Phil-Murrah F1 (*n* = 29)	Phil-Ravi F1 (*n* = 12)
Milk yield	259.40c	1804.40a	705.60b	623.10b
Lactation length	200.81b	348.48a	259.45b	233.67b

Any two means with the same letter in the row are not significantly different ($P > 0.05$).

Table 8.20 Performance (means) of Murrah and crossbred buffaloes in Taiwan. (*Source*: Liu, 1978.)

Traits	Murrah	F1 cross	G1 backcross to Murrah
Birth weight (kg)	33	32	32
Weight at 10 months (kg)	301	265	270
Total milk yield (kg)	1518	824	1015
Lactation period (days)	240	240	240
Milk yield per day (kg)	6.3	3.4	4.2
Peak milk yield (kg)	8.0	4.6	6.0

Table 8.21 Pubertal performance (means ± SD) of the Philippine Carabao, Phil-Murrah F1, and Phil-Ravi F1, crossbreds. (*Source*: Momongan *et al*., 1994.)

Parameters	Philippine Carabao (*n* = 21)	Phil-Murrah F1 (*n* = 21)	Phil-Ravi F1 (*n* = 7)
Age at development of first follicle (days)	966 ± 193a	684 ± 84b	676 ± 89b
Age at the commencement of first behavioural oestrus (days)	1348 ± 406a	881 ± 177b	761 ± 120b
Age at first ovulationc (days)	1367 ± 424a	907 ± 172b	774 ± 114b
Weight at puberty (kg)	282 ± 32b	362 ± 48a	340 ± 60a

a,b Means with different superscripts within row are statistically significant ($P < 0.05$).
c Age at puberty, based on palpation of corpus luteum to assess ovarian development.

examined concerning the suitability and farmer acceptance of crossbred buffaloes.

Reproduction

Prepubertal and Pubertal Performance

The Phil-Ravi F1 and Phil-Murrah F1 crossbred heifers reach puberty at 593 (19.8 months) and 460 (15 months) days earlier, respectively, than the Philippine Carabao heifer. The weight advantage of the crossbreds over that of the Philippine Carabao is about 58 kg for Phil-Ravi F1 and 80 kg for Phil-Murrah F1 (Table 8.21). In both the genotypes, follicular development occurred much earlier than the commencement of first behavioural oestrus as determined by a vasectomized bull together with other physiological manifestations of heat.

In terms of the development of the reproductive tract, the Phil-Murrah F1 and Phil-Ravi F1 crossbreds exhibited no significant difference in anatomical measurements compared with those of the Philippine Carabao, indicating that size and weight of the animal at puberty had no bearing on the development of the reproductive tract in buffaloes (Table 8.22). No significant difference was observed among the Philippine Carabao, and Phil-Murrah and Phil-Ravi F1 crossbreds in diameter of the cervix, size of the body and horns of the uterus, as well as the size of the ovaries.

Liu (1978) also claimed that Murrah and Murrahswamp crossbreds reached the age of puberty earlier than the local Chinese swamp buffaloes. He reported the age at puberty for Murrah to be 431 days (range: 314643); for Murrah × Chinese swamp 674 days (range: 3841203); and for Chinese swamp buffalo 1045 days (range: 6591387).

Postpubertal and Postpartum Reproductive Performance

The Phil-Murrah and Phil-Ravi F1 crossbreds conceive and give birth to calves 1 year earlier than the Philippine Carabaos. The ages at first

Table 8.22 Anatomical measurements (means ± SD, cm) of the reproductive tract of the Philippine Carabao, Phil-Murrah F1 and Phil-Ravi F1 crossbreds at puberty. (*Source*: Momongan *et al*., 1994.)

Parameters	Philippine Carabao (n = 21)	Phil-Murrah F1 (n = 21)	Phil-Ravi F1 (n = 7)
Diameter of the cervix	2.26 ± 0.54	2.12 ± 0.53	1.80 ± 0.29
Diameter of the body of the uterus	2.22 ± 0.44	2.19 ± 0.52	1.83 ± 0.36
Diameter of the mid-portion of the horns of the uterus			
Left horn	1.74 ± 0.33	1.83 ± 0.48	1.61 ± 0.40
Right horn	1.75 ± 0.33	1.84 ± 0.49	1.61 ± 0.40
Dimensions of the ovaries (L × W)			
Left ovary	1.95 × 1.59	1.90 × 1.52	1.84 × 1.26
Right ovary	1.90 × 1.60	1.90 × 1.47	1.83 × 1.24

L = length; W = width.

calving were greater than those reported by Momongan (1985)44.8 months (range: 32.461.7) for river buffaloes and 54.6 months (range: 45.763.6) for swamp buffaloes. Momongan *et al*. (1984) reported the age at first calving for Carabaos under village conditions as 63.6 months and Momongan (1985) as 66.0 months. There is no significant difference in the number of services per conception and in the length of gestation period among Philippine Carabaos, Phil-Murrah and Phil-Ravi F1 crossbreds.

After calving, there is no significant difference between the Philippine Carabao, Phil-Murrah F1, and Phil-Ravi F1 crossbreds in terms of length of time for the uterus to involute, the recurrence of follicular development, manifestation of first behavioural oestrus and development of corpus luteum in the ovary. However, it seems that more Phil-Murrah F1 crossbreds exhibited silent heat because there were instances when the CL could be palpated but the animals were not observed to show signs of heat. The Phil-Ravi F1 crossbreds have a shorter service period and calving intervals compared to Phil-Murrah F1 crossbred and Philippine Carabao, although these differences are not statistically significant ($P > 0.05$). The calving interval reported in this study was longer than that reported by Momongan (1985) who recorded it as 482.4 days (range: 430551) for river buffalo and 567 days (range: 448726) for swamp buffalo. In a study conducted under the village conditions, Momongan (1985) reported that the calculated calving interval for 82 multiparous cows was 26.3 ± 12.2 months (range: 11.557.5).

Draught Animal Power

According to Liu (1978), about 45 000 crossbreds, between swamp buffalo and Murrah, had been produced in southern China with the intention of producing more milk and meat, in addition to draught power. These crossbreds were equal in heat tolerance to the local swamp buffaloes and were superior in draught power, both in terms of speed and area per unit of time at ploughing.

De Los Santos & Momongan (1987) conducted two experiments to evaluate the draughtability of the Philippine Carabao as compared with Phil-Murrah and Phil-Ravi crossbreds. In one experiment, each buffalo was simultaneously made to carry a pack load equivalent to 20% of its body weight and made to walk a premeasured distance of 6 km. This was repeated 12 times. In a second experiment, each buffalo was simultaneously made to pull a sledge with a load equivalent to 50% of its body weight over a fixed distance of 1.6 km. This was repeated 20 times. Results indicated that, in general, the crossbreds were comparable to the Philippine Carabaos as draught animals in terms of resistance to work stress and docility. There was no significant difference among the three genotypes

in terms of initial and final pulse rates, respiration rates and body temperatures (PRT). As expected, the load stress increased the PRT significantly ($P < 0.01$) after work within breeds. Among genotypes, however, the differences were not significant indicating that all the three genotypes react similarly to work stress.

Garillo *et al*. (1987) compared the ploughing ability of the Philippine Carabao and Phil-Murrah crossbreds steers. Four mature Philippine Carabaos and four Phil-Murrah crossbred steers (weighing about 520 kg and 47 years old) were evaluated for draught power to plough under wet and dryland conditions. PRT changes before, during and after the ploughing were recorded. There was no significant difference ($P > 0.05$) between the ploughing ability of the Philippine Carabao and Phil-Murrah crossbred in terms of depth, width and velocity of ploughing, as well as draught force and drawbar horse-power. Moreover, no difference was observed on the PRT measurements of the Philippine Carabao and Phil-Murrah crossbreds as influenced by ploughing either under wet or dryland conditions.

Sarabia & Momongan (1993) evaluated the draughtability of the Philippine Carabao and Phil-Murrah F1 crossbred under lowland rainfed condition. A total of eight untrained intact buffalo bulls, four Philippine Carabaos and four Phil-Murrah F1 crossbreds, with an age range of 48 years, were used. The animals underwent a training period. They were subjected to back-riding, pulling a sledge and ploughing activities. Their responses to back-riding and ploughing activities were not significantly different ($P > 0.05$). The Philippine Carabao pulled the sledge continuously for 42.75 minutes, before it stopped and refused to move forward. The Phil-Murrah F1 lasted for only 38.35 minutes. The difference in time was significant. The animals were subjected to draught activities such as pulling a sledge and ploughing. Each buffalo was simultaneously allowed to pull a sledge with a load equivalent to 50% of its body weight until it refused to pull its load. Results showed that no significant difference was observed among the behavioural (first manifestation of refusal to walk) and physiological (onset of salivation and panting) responses of the two genotypes to stress. Furthermore, no significant difference in the ploughing ability between the two genotypes was observed in terms of pull (kN), draught force (kN), speed (m/s), draught power (kW or hp), depth and width of ploughing and area ploughed/hour. This indicates that the crossbreds are as adaptable to work as the Philippine Carabaos when exposed to similar conditions.

Crossbreeding to Combine Draught Power and Milk Production.

During the last quarter of the twentieth century there have been various attempts in different countries to cross swamp buffaloes with Murrahs to produce crossbreds for draught and milk production. Although buffalo crossbreeding and selection among crossbreds for milk production appear to be promising from the genetic point of view, it is worthwhile considering the comparative economic advantage of milk production from buffaloes versus dairy cattle crossbreds or purebreds in many countries, especially in Southeast Asian countries. Buffaloes, both crossbreds and purebreds, on an average, produce less milk than, say, the Holstein crossbreds. For example, Murrahs in Thailand averaged 806 kg per lactation, while Holstein crossbreds in the same environment (F1 and F2) produced at least two to three times as much during the same year.

It is questionable whether a high priority should be given to the selection of swamp buffaloes for milk production. However, if the development goal is to improve the nutrition and health of rural people through upgrading of swamp buffaloes for household milk consumption, the breeding goal becomes a dual-purpose animal both for draught and milk production. Many reports indicate the superiority of crossbreds in milk production but information on their draughtability and acceptance by farmers is still lacking -39% of the farmers in one region of the Philippines rated the crossbreds poorer than, 24% better than and 14% equal to swamp buffaloes.

It should also be noted that some part of the superiority of milk yield of the crossbreds over swamp buffaloes is due to differences in feeding and management. The performance of crossbreds under village farm conditions needs to be evaluated. What will be the nutritional requirements of working buffaloes if they are also used for milking? Can the village farmers provide the additional feeds required without negative socio-economic impacts on other aspects of farm production? These are some of the questions which need to be researched before embarking on large-scale massive crossbreeding programmes with swamp buffaloes.

Health

When compared with other domestic livestock, the water buffalo generally is a healthy animal. This is particularly impressive because most of them live in hot, humid regions that are conducive to diseases. The buffalo is a bovine and is susceptible to most of the diseases and parasites that afflict cattle. Although the reasons are not specifically known, the effect of diseases on the buffalo and its productivity is often less deleterious than on cattle in the same ecosystem.

Antibiotics and vaccines developed for cattle work equally well on buffaloes. As a result, treatments are available for most of the serious diseases of buffaloes, although some are not very effective for either.

The major cause of losses in buffaloes is due to calf mortality. Newborn buffalo calves, like bovine calves, succumb in large numbers to viruses, bacteria and poor nutrition. This is largely due to poor management during the calf's first 2 months of life, e.g. depriving calves of mother's milk and proclivity for wallowing which exposes calves to waterborne diseases. Further, a young one occasionally drowns when an adult rolls on the top of it.

In countries such as the Philippines, Vietnam, Kampuchea, Laos, Malaysia, Thailand, Myanmar and India, buffaloes, as reported by several workers, are highly susceptible to rinderpest, and may be even more so than the indigenous cattle managed under comparable conditions. In southeastern Europe, however, the buffalo is relatively more resistant than the local cattle breeds. In the broadest sense it seems that, subject to local and regional variations, the susceptibility of the buffalo to rinderpest increases from Western to Eastern Asia (Vittoz, 1951). The clinical syndromes and autopsy findings are more or less similar to those observed in cattle. However, the body-temperature curve in the buffalo is quite often erratic. Clinical symptoms tend to be more acute and as a rule the conjunctivae are more severely congested.

In general, buffaloes are less susceptible than cattle to foot-and-mouth disease. Nevertheless, severe outbreaks among buffaloes are not uncommon, and in countries like Laos and the Philippines more buffaloes were affected than cattle in some of the past epidemics.

Water buffaloes are highly susceptible to pasteurellosis, or haemorrhagic septicaemia, caused by the bacterium *Pasteurella multocida*. Haemorrhagic septicaemia runs a more acute course in buffaloes than in cattle and the oedematous form is more common. Buffaloes are more susceptible to it than cattle and die in large numbers when affected by pasteurellosis. A vaccine against pasteurellosis is effective in protecting both buffaloes and cattle and it is cheap and easily made.

Reports on the incidence of anthrax in buffaloes vary from country to country. In Egypt the disease appears to be rare in buffaloes. In India also the disease is less common in buffaloes than in cattle. The situation is just the reverse, however, in Myanmar where buffaloes frequently contract the infection. This poses a serious danger to the elephants working in adjacent forests. On some islands in Indonesia the disease occurs in a severe form and affects buffaloes more than cattle.

Several workers have reported that the buffalo is relatively less resistant to tuberculosis. This is one of the most important diseases affecting buffaloes in Egypt, the incidence being higher in housed buffaloes in the southern region. Slaughterhouse examinations of carcases in a Cairo abattoir showed that about 7% of the buffaloes slaughtered had tuberculous lesions. Tuberculo-

sis tests carried out in four representative areas in India on 44 519 cattle and 40 201 buffaloes under comparable conditions of management showed 4.7 and 13.8% reactors, respectively, in the two species (Lall *et al*., 1969).

The incidence of tuberculin reactors in India is higher in buffaloes than in cattle (Lall *et al*., 1969). Mammalian tuberculin evokes a stronger reaction in buffaloes on intradermal test as compared to that in cattle (Lall, 1946). Other strains of mycobacteria have been isolated from feral buffaloes and cattle in northern Australia but seem to have little effect on the animals. Tuberculosis occurs among buffalo herds of the world only because more of them are kept under unsanitary conditions.

Mastitis is one of the serious diseases of the buffalo, especially in countries where buffaloes are mainly kept for milk production. A mastitis survey carried out on 690 buffaloes in nine dairy herds in different parts of India showed an incidence of 20.7% of subclinical or insidious cases and 2.4% of clinical cases. In another random survey of 1193 buffaloes in the northern part of India, Katra & Dhanda (1964) found an incidence of infection of 11% in the urban and 9% in the rural areas. The corresponding data for 3097 cows were 10 and 7.5%. About 98% of the cases were caused by pathogenic staphylococci and streptococci while the remaining 2% of the cases were due to other organisms. In Egypt, incidence of mastitis in the two species was virtually the same (Wahby & Hilmy, 1946). In one survey 9% of 860 buffaloes brought to the Cairo clinic were affected with mastitis (El-Gindy *et al*., 1964). Treatment and control programmes used for cattle are equally effective for buffaloes.

Brucellosis

Brucellosis is fairly common in buffaloes. In a survey of 13 565 animals in military dairy farms in India, 10% of the buffaloes and 13% of the cows recorded positive reactors on serological tests. In Turkey, 42% of the 31 buffaloes and 39% of the 285 cattle, and in Brazil 41% of buffalo serum samples gave a positive reaction on agglutination tests (Golem, 1943; Santa Rosa *et al*., 1961). In Egypt cultures of *Brucella abortus* were isolated from as many as 15% of 200 buffalo milk samples subjected to bacteriological examination (Zaki, 1948). In Indonesia, however, brucellosis is sporadic in buffaloes, although it is endemic in cattle. Brucellosis in Venezuela is increasing more rapidly among buffaloes than among cattle. As many as 57% of some Venezuelan herds are infected with the disease. It is a frequent cause of abortion in buffaloes. Serologic procedures and measures developed for the control of the disease in cattle are also an effective means of curbing this infection in buffaloes. (Consumption of raw milk or contact with aborted fetuses may cause undulant fever in humans.)

Ticks

Buffaloes are notably resistant, although not immune, to ticks. Buffaloes appear to be less affected by ticks than are cattle. Warble infestation is also less prevalent in buffalo (Sen & Fletcher, 1962). In a tick-infested area of northern Australia only two engorged female ticks were found on 13 adult buffaloes during a 2-year test. Accordingly, healthy buffaloes are not commonly affected by diseases borne by ticks nor are the hides damaged by their bites. Since ticks are rarely found on buffaloes, anaplasmosis, theileriasis and babesiosis, that are tick-borne, have little effect on buffaloes in the field. Buffaloes and cattle are equally susceptible, however, if inoculated with East Coast fever, a form of theileriasis. This is important because tick infestations in cattle are particularly troublesome in the tropics and the pesticides used to control them are becoming ineffective as the ticks develop resistance. The pesticides are also becoming expensive. The basis of the buffalo's tick resistance is not known, but wallowing and rubbing may play a role in it; animals kept in experimental concrete pens in Australia have developed heavy tick infestation.

Screw-Worm

Larvae of the screw-worm fly (*Callitroga* spp.), a major pest of livestock in Central and South

America and some other tropical areas, do not affect adult water buffalo. In Venezuelan areas where zebu-type cattle are severely infested, adult water buffaloes are virtually free of screw-worm larvae and the umbilicus of newborn calves seldom, if ever, becomes infected. The same is true in Papua New Guinea. It is thought that the mud plaster produced by wallowing suffocates the larvae. In India screw-worms do not affect water buffaloes either, and there they wallow in fairly clear water and the farmer usually washes them off.

Roundworms

Neoascaris vitulorum is a commonly occurring helminth parasite of buffalo calves and can cause considerable mortality in young stock. The heavy losses of young buffalo calves throughout the world are caused, in large measure, by the roundworm *Toxacara vitulorum*. The calves are more susceptible than mature animals and they become infected before birth or within 24 hours after birth through the mother's colostrum. The roundworm is the most serious buffalo parasite and in untreated calves the small intestine can get packed with worms to the point of complete occlusion. Anthelmintic drugs that control roundworms are highly effective and widely available.

The adult water buffalo appears to have a high degree of resistance to strongyloid nematodes. Being such excellent converters of rough fodders they do not suffer the nutritional deficiency and the resulting liability to these roundworms experienced seasonally by cattle.

Liverfluke

Fascioliasis, or fluke infection, is another important disease of buffaloes. In India *Fasciola gigantica* infestation is predominant in the plains while *F. hepatica* is mostly confined to the hilly tracts. In a survey lasting from 1949 to 1953 in Thailand, 7% of 29 421 buffalo livers were found to be cirrhotic due to fluke infestation. In Singapore a large number of buffaloes imported from Thailand were found to be infected with liverfluke. Fascioliasis is also common in the Ararat valley in Azerbaijan in the former USSR, as it is in the Philippines. During wallowing, water buffaloes can easily become infected with water-borne infective stages of liverfluke (*Fasciola hepatica*). Although the number of flukes in a buffalo may be phenomenally high, no clinical signs of the disease are usually evident. It seems likely that the resulting liver damage reduces the growth, the work and milk production of buffaloes more than is generally appreciated.

Trypanosomosis

Among the protozoan parasites, *Trypanosoma evansi* appears to be the most important for the buffalo, especially in Southeast Asia. This micro-organism generally causes a latent or subclinical form of trypanosomosis, but severe outbreaks characterized by high temperature, signs of abdominal pain and mortality 612 hours after the onset of the symptoms have also been recorded. The water buffalo is susceptible to trypanosomosis and is reportedly more susceptible than cattle to *Trypanosoma evansi*. Experience with this animal in Africa is limited, but trypanosomosis may be the reason why Egypt is the only African country that has traditionally employed water buffalo.

Heavy mortality in buffalo calves due to coccidiosis has been reported from India and Sri Lanka.

Other Parasites

The wallow and its resulting mud-cake seem to protect water buffalo from many biting files, but the main ectoparasite in Australia and Southeast Asia is the buffalo fly (*Siphona* spp.). Pediculosis, caused by the sucking louse (*Hematopinus tuberculatus*), occurs widely among buffaloes. Sarcoptic manage (*Sarcoptes scabiei* var. *bubalus*) is a serious disease, especially among calves and during dry seasons when wallowing opportunities are restricted. The lungworm *Dictyocaulus viviparus* thrives in warm, humid areas and sometimes infects buffaloes heavily, although its outward manifestations are rare.

Management.

Water buffaloes are easily adaptable and are managed in many ways. The system may vary from intensive in many parts of Western, Southeastern and Eastern Asia to a form of ranching in some areas of South America. In general, they are raised like cattle. But in some operations they must be handled differently.

Water buffaloes are managed in 'backyards' in Asia under intensive management systems in herds of 250 animals by small and marginal farmers and around urban centres in herds of 2050. They exist on the resources of small holdings. Management and expenditures are minimal. Care of the family buffalo is usually entrusted to children, old people, or women not engaged in other farm duties; the buffalo provides an opportunity for them to be useful and productive.

The buffalo fits the resources available on the farm, but is also an urban animal. Thousands of herds of 220 buffaloes may be found in the cities and towns of India, Pakistan and Egyptall fed, managed, and milked in the streets.

The buffalo has important qualities as a feedlot animal; it can be herded and handled with relative ease because of its placid nature. The buffaloes of the small and marginal farmers of India, Pakistan, Sri Lanka and Egypt are fed and milked by their owners under feedlot-like conditions in their villages. Many of Italy's 100 000 buffalo are maintained under similar conditions. Wherever buffaloes are raised as dairy animals for milk production, they are housed, managed and fed individually with great care.

As thermoregulatory mechanisms are poorly developed in buffaloes, they suffer thermal stress during hot weather. Therefore, they need to wallow or be splashed with water in order to keep their bodies cool. If this is not done, they show summer infertility or anoestrum. It has been found that buffaloes have a normal oestrous cycle during summer if they have access to water. Generally, for minimizing thermal stress during hot weather proper shelter or housing is provided in order to avoid direct solar radiation. Washing/wallowing/sprinkling/splashing or showering with water helps to lower body temperature. Cool drinking water is provided along with cooling devices, e.g. wet curtains or panels of air coolers or fans. Trees or landscaping around the shelter reduce ambient temperature. Feeding green fodder, silage, or hay is generally helpful and should be done at relatively cooler times, e.g. in the morning or late evenings. Providing concentrate feed at night, grazing only if green feeds are available and regular mineral mixture supplementation also help.

Shelter Space

Buffaloes need more standing space than cows. A shed measuring 24 m2 should be able to comfortably house six buffaloes. The walls of the shelter should be about 1.52 m high and be cement plastered. This will make them dampproof. The roof should be 34 m high in order to allow good ventilation. The roof can be supported on pillars. The floor should be hard, impervious and well drained to remain dry and clean. The manger (feeding space) should be 1 m long, 0.5 m high and with a depth of 0.25 m. The corners of the manger or feeding trough should be rounded to avoid injury to the feeding animal and for easy cleaning. A sprinkler should be provided in the loafing area or a wallowing tank big enough to accommodate six buffaloes. The water in the tank should be clean. There should be a regular and abundant supply of clean drinking water as well as enough water for splashing, sprinkling and showering if a wallowing tank is not provided. This should be done three to four times a day in hot weather. Overcrowding of animals should be avoided.

Water Requirement

Buffaloes require more water than cows. Water consumption is at a maximum in the summer, much less in the winter and the rainy season. Normally a buffalo consumes about 75 litres a day in summer compared with 60 litres in rainy

weather or the winter season. The consumption of water is related to dry matter consumption. On average each kilogram of dry matter consumed requires 5.5 litres of water during the rainy season when humidity is high.

Calves

Mortality

Calf mortality in early age is very high under village conditions and at private dairies in towns and cities. Disease and negligence on the part of the farmers are factors responsible for the high death rate in neonatal calves. Under artificial rearing, mortality can be reduced significantly. In the case of urban centres of production, however, mortality is induced in calves in India, Pakistan, Bangladesh and Sri Lanka. This is to avoid the cost of calf raising. They are deliberately starved of milk and die due to starvation so that owners save the expenditure of raising them, for which they neither have space nor wish to invest in their feeding.

Care at Birth and Management up to 2 or 3 Months of Age

The following management practices should be followed at birth and during the first 2 or 3 months of life.

• Immediately after birth the nose and mouth of the calf must be cleaned of membranes in order to facilitate easy breathing. After cleaning the calf should be left with the mother who will lick it dry.

• Tincture of iodine should be applied at the end of the broken umbilical cord in order to avoid the risk of infection which may cause navel ill. In case of an intact umbilicus, it should be severed with a sterile knife at a distance of about 68 cm from the umbilicus before applying the tincture of iodine.

• In emergency cases due to arrested breathing, measures should be taken to induce breathing by artificial means, i.e. by blowing air into the mouth of the calf or by lifting the calf from its hind limbs with a sudden jerk.

• A light bedding of straw, dry grass, wood shavings, etc., free from nails and sharp material should be provided for dam and calf. Dry ash is also used in villages during the rainy season in order to keep the *kuchha* floor dry. It is advantageous to keep newborn calves in individual pens for the first 34 weeks of life. These should measure 1.0 × 1.5 m and be kept clean, well ventilated and dry. At 1 month of age the calves can be housed in convenient size groups. Under village conditions in India, young calves are usually tied up some distance from their dam and when old enough are moved to the manger to eat with older animals.

• Small farmers do not usually practice a specific marking system but on large farms some method of identification is essential. Possible identification methods are: ear notching, branding, (usually on the dorsal surface of the hoof or the horn, or on the hindquarters), tattooing (on the interior surface of the ear or the ventral surface of the tail) and tagging (with a disc fastened in the ear or to the neck collar). For details see Appendix 1.

• Dehorning is not generally practised in buffalo management. If required, however, it should be completed at an early age. Any of the methods used for dehorning cows can be used to dehorn buffaloes.

• Supernumerary teats are not uncommon in buffalo heifers and such teats should be extirpated surgically during early life (13 months after birth).

• If calves are to be early weaned it is necessary to teach them to drink from a container. This is done by allowing a calf to suck the finger of the farmer, who then guides the muzzle of the calf into the warm milk in the container. Once the calf suckles a little milk in this manner it usually becomes easy to train it to feed. The training period can last from 2 to 7 days.

• When calves are housed in calf pens provision should be made for exercise; possibly the use of a paddock. Under these circumstances arrangements must always be made for the provision of drinking water, shelter and, if possible, a wallow.

• Training buffalo calves for leading should commence at 2 to 3 months of age. In Indian villages calves are tied by the leg for the first 3 or 4 weeks of life and are then allowed to follow the grazing herd.

Feeding

On small farms calves may be suckled until weaned, but on larger farms after suckling to obtain their colostrum, calves will usually be fed their milk from a container. As strict hygiene measures as are possible should be adopted. Utensils should be clean and dry and if possible sterile. The milk to be fed should be boiled and cooled to body temperature (39°C) before feeding. During their first week of life calves should be fed three or four times a day, reducing to twice a day by the end of the second week until they are 3 months of age. Overfeeding must be avoided. Calves should be provided with a source of fresh water, good quality hay, preferably in a rack, and a concentrate feed. Milk should be gradually removed from the diet until it is reduced to zero on about the sixtieth day of age. The concentrate feed is gradually increased until the calves are consuming about 1.52.0 kg per day at 3 months of age. Details of medication that may be required are shown in Table 8.23.

Diseases

Mortality in young buffalo calves is a serious problem under village conditions as well as on organized farms. Buffalo calves when young are lazy and slow and require more attention from the herdsman. Any negligence in feeding and management results in heavy loss of animals. About a quarter of the calves born are lost in the first 3-month period in India. Mortality is greater in male calves because they are neglected by their owner from the very first day of birth.

Pneumonia

Pneumonia is one of the major causes of mortality of young calves especially during the rainy season and winter. Mortality due to pneumonia has been reported to be 33.841.3% of total calf mortality (Verma & Kalra, 1974; Sharma & Singh 1975). The predisposing factors are poor health, exposure to draft, wet bedding and

Table 8.23 Feeding and medication of buffalo calves from birth to 11 days of age. (*Source*: Bhosrekar, 1993.)

Age (days)	Colostrum/milk (litres)	Medication	Prevention against
1	2	(1) Aureomycin or Terramycin or Steclin or nitrofurazone or Terramycin with antigen 77	Scour
		(2) Sealing of navel cord with Tincture of iodine	Navel ill
2	2	Vitamin A supplement (Revisol, Rovimix, Vitablend, fish liver oil)	Night blindness
3	2	(1) Piperazine adepate	Ascariasis
		(2) Enterovioform	Dysentery
7	2	Piperazine adepate (if not given on 3rd day)	Ascariasis
811	2	Sulmet	Coccidiosis

dampness in the house, and weakness due to other diseases. The infection may be viral or bacterial. High temperature (103106°C) associated with copious nasal discharge, coughing and rapid breathing are the apparent symptoms. The muzzle becomes dry and dull. An infected calf should be immediately removed to an isolation house and the pen or stall should be thoroughly cleaned and disinfected. A sick calf should be kept in a warm, dry house and a veterinarian consulted.

Gastroenteritis (Diarrhoea, Scour, Enteritis, Etc.).

This is an equally fatal cause of neonatal mortality in buffalo calves. The incidence at organized farms has been found to be 3235% (Verma & Kalra, 1974; Sharma *et al*., 1975). It may be non-infectious due to indigestion following overfeeding or the feeding of spoiled grain mixture and hay, or it may be an infectious scour caused by virus, bacteria or parasites. Symptoms are severe diarrhoea; yellowish white faeces with a very offensive smell. In severe cases blood and mucus also appear in the faeces. These are followed by prostration, extreme weakness, dehydration and death. A veterinarian should be consulted.

Ascariasis

Death due to a heavy load of roundworms is very common in young buffalo calves in villages. The incidence of ascariasis has been reported in neonatal calves. Deworming at about 1 week of age has been found to be very effective.

Records

The following records should be maintained from the birth of the calf:

- A calf register with details of birth date, sex, liveweight, identification number, dam and sire numbers.
- Individual history card. All details including health.

Heifers

Buffalo heifers are the valuable replacement animals and receive special attention of farmers right from their birth. Care and management significantly influence the production performances of heifers. Under village conditions, the age of heifers at first conception varies widely depending upon feeding and management practices. The average age at first conception is 1820 months under good management. Age at first calving may vary from 2860 months though heifers under good management should calve at about 2836 months of age and at 300350 kg liveweight. Mean daily gain in body weight from 12 weeks of age to 12 months of age is around 500 g per day. The average liveweight of farmbred buffalo heifers at 1 year of age ranges from 200 to 300 kg depending on the breed, climatic conditions and region.

Factors Affecting Growth Rate

Fodder

On *ad libitum* feeding of legume forage like berseem, lucerne, cowpea and weeds like ghiabati (*Ipomoea pestigridis*), growing heifers may gain about 370 g daily. Supplementation with a small quantity of energy-rich concentrate mixture significantly improves the rate of daily gain in liveweight.

Shelter and Water Sprinkling

Buffaloes are very fond of wallowing. However, under limited conditions of intensive rearing or the keeping of small herds in towns and a few head (one to five or more) by farmers, it is not practicable to provide wallowing ponds. Under such conditions animals are washed once or twice a day, depending upon the atmospheric conditions, or water is sprinkled over their bodies. Water sprinkling has a significant effect on the growth of heifers. Similarly if shelter is provided against direct solar heat, growth performance is dramatically improved, particularly

if the shade is provided by the thick foliage of large trees.

Housing

At organized dairy farms heifers are usually managed in a loose housing system. Space requirements are shown in Table 8.24. Heifers may also be managed in standard stalls, about 1.5 m in width, with facilities for watering, feeding and grooming.

Feeding

When the production potential of the dam of the heifer concerned is not known, the average of the breed is used for the calculation of the ration of heifers in their last month of pregnancy. Usually, when straws and poor quality hay are the roughage source, pregnant heifers are fed 1.52.0 kg of a concentrate mixture, depending upon the availability of a small amount of green feed. Concentrate feeding should be increased gradually during the 1520 days before calving to 45 kg per day for a milch breed of buffalo.

Care at Parturition.

The heifer should be removed to a disinfected loose box 2 weeks before calving. Three days before calving, a laxative and light ration with a increasing proportion of bran and molasses in the diet should be fed. The actual calving should take 2 hours and should be watched from a distance as heifers tend to be nervous. If the fetal bag is not ruptured is should be opened and a veterinarian summoned. After delivery, the heifer should be given a bucket full of fresh water followed by warm mash made from bran, cracked wheat or corn, molasses, salt, ginger and a mineral supplement. This will restore vigour and help in cleaning the bowels. The placenta is normally expelled 46 hours after delivery. It should be removed and immediately buried, otherwise heifers are known to eat it and suffer from impaction of the rumen. If the placenta is retained for more than 24 hours a veterinarian should be summoned.

Bull Calves

In India male buffalo calves are usually neglected from the first day of their life and those who survive the stress of bad management, insufficient feeding and neglected conditions are used either for draught purposes or are slaughtered for meat. Male buffalo calves are normally allowed full feeding on the udder only for 35 days after birth and thereafter they are just allowed to suckle for 23 min to stimulate the let-down of milk. This practice of milk feeding male calves is followed as long as they survive. It is common in the small private dairies in towns. The average birth weight of male buffalo calves is 30 kg and they hardly reach 100 kg liveweight at about 1 year of age under neglected feeding and management, whereas heifers maintained at organized dairy farms attain liveweights of 200250 kg at the same age. Bull calves that survive are ultimately reared in a similar manner to heifers.

Table 8.24 Space requirements of heifers. (*Source*: Bhosrekar, 1993.)

Physiological stage	Floor space (m2)		Manger length (cm/animal)
	Open area	Cover area	
Young heifers	56	1.01.5	4050
Pregnant heifers (early pregnancy)	810	34	5075
Pregnant heifers (late pregnancy)	Kept in calving pen during the last 14 days and after parturition should be moved to lactating animals shed		

Those used for ploughing and other traction work are usually castrated at about 1 year of age. Those to be fattened for slaughter should be fed good quality feeds and fodders.

Care of Breeding Calves

Selected bull calves are reared to provide future breeding bulls for use in natural service and artificial insemination (AI) centres. At about 56 months of age these bull calves should be separated from the heifer calves. At this stage bulls require special training so that they can be led to a dummy for semen collection or be moved conveniently in a show ground when needed. Head collar or neck roping should be used for a short time to lead them on a road at short intervals, so that they learn to move freely and normally. After 56 months of age bull calves should be exercised for 30 min in a group in a bull exerciser or at some other suitable place. In the beginning a seasoned bull should be used to lead the young ones for a few days. The period of exercise should be increased gradually to about 1 hour per day which is adequate for bulls in regular use. A shelter area of 56 m2 is ideal for the diversified climatic conditions of India, when bull calves are more than 1 year of age. Bull calves can be kept in groups of 1015 until they are about 2 years of age in loose housing with adequate open space.

Feeding

Bull calves kept for breeding should be fed liberally a fairly rich ration consisting of a grain mixture and good fodder to ensure a daily gain of 500700 g in liveweight so that they attain a liveweight of 300350 kg at about 2 years of age when they can be used for breeding purposes.

Insertion of Nose Rings and/or Rope Strings

For easy control and handling of bulls, a metallic ring or rope string is inserted in the nose through the cartilage of the nasal septum. In India metallic rings are inserted in the nose of breeding bulls and rope strings are used for working bullocks or bulls. The ring should be inserted in the nose of young bull calves at 812 months of age. Nose rings are made of non-rusting metals like copper and brass for young bulls and gun metal for adult and unruly bulls. A light- or medium-weight ring of 56 cm diameter is inserted in the young bulls to be replaced by a heavier ring of 68 cm diameter at about 2 years of age.

Ringing of bulls is not difficult and a ring can be inserted by a skilled farmer. The bull calf is secured in a stanchion and a sterilized trocar and cannula is used to put the ring in place. After putting in the nose ring it takes about 810 days for healing and the bull should be tied or led only after complete healing, in order to avoid further injury and delay in scar formation. In village conditions a large-sized needle, with a wide eye at the distal end, is used for inserting a rope string in the nose of working buffaloes. Rings are also available with a sharp pointed end which pierce the cartilage when pushed at the time of insertion.

Occasionally an unruly bull pulls the ring out of his nose, tearing the nasal septum. There is no perfect remedy for such an accident. In some cases rope string passing a little high in the nasal septum and tied behind the horns may serve the purpose of handling and leading.

Pregnant Cows

Special attention of the farmer is required for the watchful care of pregnant animals during the last quarter and at calving time so that they are comfortable. On average Indian buffaloes carry their calves for a period of 305 days but the gestation period may range from 290 to 320 days from date of service (conception). Buffaloes should be dried off at at least 68 weeks before calving. No concentrates and only poor quality roughage should be fed. Milking should be reduced to once a day and ended after a 710 day period. During the dry period cows should be fed a liberal ration consisting of 23 kg of concentrates and good quality roughage.

Calving

It is essential to calculate the approximate date of calving from the breeding records (if they exist) and to move the cow into calving accommodation, that has been thoroughly cleaned and disinfected, some 35 days in advance of the expected calving date.

The calving accommodation should have a floor space of 910 m2 and the cow should be left to calve by herself, though a constant watch should be kept. If there are major difficulties during birth a veterinarian may be required. The placenta is expelled after about 46 hours and the newborn calf should be allowed to suckle and obtain colostrum within 4 hours of birth.

After parturition the cow may wish to drink a large quantity of water and should be fed a laxative diet for a few days. As the milk production of the cow increases the feeding schedule should be changed at about 710 day intervals.

First Calvers

Usually the milking buffaloes which have calved for the first time need special attention from the milker in handling and approaching. Buffaloes are easily trained in comparison to cows and they can be milked in a milking shed or elsewhere. It is a common scene in Indian towns to see the door-to-door milking of buffaloes by small dairy keepers. At large farms the following training should be given to all pregnant heifers:

• They should be taught to enter the milking stall in a queue. For this purpose they should be led by three or four experienced buffaloes.

• Each heifer should be assigned a definite place and be brought every day only to her assigned place.

• The milker should spend a few minutes with each heifer about 1520 days before calving and the heifer should be gently approached by patting her on the back or on the loin. In due course her udder and teats should be gently rubbed and pulled.

• After calving, heifers should be handled gently otherwise it may be difficult to milk a hard milking animal. Shouting or striking is always harmful as such treatment leads to the witholding of the milk.

• The udder is very tender after first calving and it should be handled gently.

• After milking buffaloes should be taken out of the milking stall in an orderly manner.

The problem of short teats is rare in buffalo heifers and if there is a case it can be corrected to some extent by regular pulling and stripping every day for a few minutes about 3 months before calving. This practice should be stopped, however, about 23 weeks before calving to avoid milk formation in the udder.

Dry Cows

The length of the lactation period in buffaloes varies from 8 to 10 months and the calving interval from 11 to 18 months. Thus, a dry buffalo has to be maintained for an average period of about 5 (28) months before the next calving. On good quality pasture no extra feeding of concentrate is required. Good grazing for 68 hours will be sufficient to meet the requirement of dry pregnant buffaloes. In the rain-fed areas of India supplementary feeding is not needed from July to October. November and December is the lean period in Central and Western India and during this period wheat *bhusa*, paddy straw and stovers of sorghum, maize or pearl millet form the main roughage diet. Under such conditions about 23 kg concentrate mixture should be fed along with *ad libitum* roughage. From January berseem and oat fodders become ready for harvesting. About 2035 kg green berseem and 34 kg wheat *bhusa* or other poor quality roughage should be fed to dry and pregnant buffaloes.

Non-pregnant dry buffaloes and breeding heifers should preferably be given protection from solar radiation by given shelter and water sprinkling or wallowing facilities to improve reproductive performance.

Buffaloes in their last 68 weeks of gestation should be separated from the dry herd and be fed on the basis of their previous lactation performance or expected yield. This technique is known as 'steaming up', which may be followed by a 'lead feeding' of a 7- to 10-day period. Lead feeding is required only for high yielding females producing 20 litres or more milk per day.

Bulls.

The bull should be reared under optimum management conditions from an early age so that it is gentle in behaviour. Training is provided from the age of 810 months by a skilled bull attendant. At this age selected bulls are housed individually in bull sheds.

Housing and Exercise

A large shed with 1012 m2 covered area is ideal for housing a mature buffalo bull. The shed should open to a paddock of 1520 m2, fenced with galvanized iron pipe, wooden logs (*balli*), barbed wire or a brick and cement wall to a height of 22.5 m. The stall in the shed should be fitted with a stanchion for holding the bull during cleaning of the stall and washing of the bull. For most of the time, however, a bull should be able to move freely in the paddock and stall. If it is necessary to tie the bull, a heavy neck strap should be used. The use of a nose ring for daily tying should be avoided. A shower bath in the stall will be convenient for washing the bull. The floor of the stall should be made of bricks or roughened concrete with sufficient slope for efficient drainage. The paddock should have levelled ground. In the Indian climate a *kacha* ground is economical and quite suitable provided proper drainage is provided to avoid mud and filth in the barn. In India, bedding is only required for the 3 to 4 winter months, during which direct wind and draft should be avoided.

A bull should be given regular exercise at a fixed time on an open ground or bull exerciser. All except unruly bulls should be led in a queue in an orderly manner. Fast walking, jumping and running for about an hour in open ground or fast movement in a circle in a bull exerciser for 5060 min every day is enough to keep the bulls active and healthy.

Feeding and Watering

Grazing for 68 hours on good pastures is adequate to maintain health and vigour. A bull on stall feeding should be fed 1520 kg green fodder or silage, 68 kg wheat or paddy straw and 22.5 kg concentrate mixture. Bulls should be provided with a liberal amount of drinking water and be washed at least twice daily in summer.

Controlled Use

A bull should not be allowed to serve or be used for semen collection unless it is about 2 years of age and 300350 kg liveweight. Use of young bulls should be limited to twice a week for semen collection or mating two female buffaloes per week. Mature bulls of over 3 years of age may, however, serve one female a day during the breeding season and semen collections may be made on alternate days. Too frequent use of bulls is often responsible for aspermia or nonmotile semen which leads to non-fertile service.

In India there are two types of bull, the one type in private ownership and the other maintained at the AI centres. The former type generally move together with the female buffalo herds in the villages. This makes it difficult to record dates of service, etc.

Management of Unruly Bulls

Almost all Indian buffaloes are gentle and docile. Sometimes, however, a bull becomes vicious. A vicious bull is troublesome and difficult to control. Usually they are disposed of, to be slaughtered or used for traction purposes after castration. If not, they are sometimes used for natural service under closely controlled conditions.

Rotation of the Bulls

In villages one to five female buffaloes are kept by farmers and in milk colonies of towns usually

2030 lactating buffaloes are maintained. Most AI facilities have been provided by the Animal Husbandry Departments of the states. Dairy farmers with more than 20 females, usually maintain a bull for breeding. Departmental bulls at AI centres are shifted from one centre to another after about 3 years of service at one centre. This practice is followed to avoid inbreeding. At larger dairy farms several bulls are maintained and breeding is recorded, reducing the chances of inbreeding so that bulls can be retained for many years. A bull can be used for up to 10 years. Muscular strength and desire continue up to 15 years of age but the number of unsuccessful services increases after 67 years of age (Cockrill, 1974).

Bullocks

Castrated, as well as entire male buffaloes, are used for draught purposes in India.

Training

Buffalo males 2430 months of age and of about 300 kg liveweight are yoked with an old and experienced bullock. The yoke is connected to a fairly heavy wooden log and the pair of bullocks are driven in a field. While training, the owner should talk and pat the animals and at the end of the exercise they should be hand fed. After a few days of empty yoke training the bullock is introduced to a plough or cart yoke together with a trained bullock. Bullocks are normally trained in 34 weeks for most agricultural operations but it is advantageous to only conduct light work in the first year of training. Cockrill (1974) has referred to examples of buffaloes continuing to work until the age of 40. On average buffalo working life is 20 years but it is not uncommon to see older animals at work.

Buffaloes usually work for 610 hours a day. It is difficult for black coloured animals to work and stay in the sun for a longer period. After work bullocks should be rested for 30 min to 1 hour before watering and feeding. Liberal quantities of fresh drinking water should be offered to the animals after return from work.

Shoeing

Unshod bullocks should not be put to work to carry heavy loads on gravelled and metalled roads, otherwise severe injury to their feet will render them unfit to work for several days. Various types of iron shoes and sometimes wooden shoes are used in different parts of the world.

Range Management.

Water buffaloes can be managed on rangelands. In Brazil, Venezuela, Trinidad, the United States, Australia, Papua New Guinea, Malaysia, Indonesia, the Philippines and elsewhere there is increasing interest in the management of buffaloes on rangelands for beef production. The production practices are similar to those used for range cattle, though water buffaloes must be able to cool off, so that shade trees are desirable and although wallows are not essential they are probably the most effective way in which buffaloes can cope with heat.

Water buffaloes are intelligent animals. The young learn behaviour patterns quickly and often are reluctant to change their habits. Feral animalseven those born in the wildtame down after a week or two in a fenced enclosure.

Provision of adequate fencing is one of the great problems of buffalo management. The animals have strong survival instincts and if feed runs short, as it may on range in the dry season, they will break through fences that would deter cattle, who would remain within the fence and starve. They will also break through the fences if their family unit is split up. Barriers must be stronger than those used for cattle and the wire of fences must be closer together and lower to the ground because buffaloes will lift fences up with their horns rather than trample them down. In northern Australia, Papua New Guinea and Costa Rica it has been found that buffaloes are particularly sensitive to electric fences, a single wire is all that is needed, and in Brazil a special suspension fence has been devised. These both seem to be cheap and efficient answers to the fencing problem.

Water buffaloes are easily managed from horseback and easily worked through a corral. Actually, because of their docility they can be mustered on foot, even on ranges where cattle require horses. Buffaloes born on the same range tend to herd together and can be mustered like sheep.

One of the major management adjustments to be made by cattlemen is understanding and capitalizing on the buffalo's placid nature. Buffaloes are naturally timid and startle easily; they must be handled quietly and calmly. Rough handling, wild riding, and loud shouting make handling them more difficult and training them harder.

The identification of individual buffaloes on the range is difficult. Fire brands do not remain legible on the skin for long. Cryobranding (freeze branding) is more durable. Most types of ear tags are not very successful; the numbers wear off and mud covers up the tag's colour. In northern Australia ear tattooing has been the most successful identification technique, with tattoos remaining legible for at least 8 years.

On the range cattle and buffaloes coexist satisfactorily. They segregate into their own groups and do not interfere unduly with one another. The buffalo herds, however, usually dominate the cattle herds and tend to monopolize areas with the best feed supply.

Feed troughs and mineral boxes used for cattle are suitable for use by buffaloes, but chutes and crushes must be widened to accommodate the buffalo's broader body and, when necessary, the swamp buffalo's greater horn spread.

Water buffaloes are powerful swimmers. In Brazil they have been known to escape from a holding by swimming down the Amazon River. An unusual management difficulty is caused by piranhas in the rivers and swamps of South America. In one herd of heifer buffaloes, 40% lost all or part of a teat to these voracious fish.

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9
Sheep

Introduction

Sheep have been kept in the tropical regions of Africa and Asia mainly for the production of meat. Secondaryor at least less widespreadfunctions are wool, hair, skin, milk and manure production. In some areas of India (Lall, 1950) and Nepal (Wilson, 1997) they are even used as pack animals and carry small loads of 2.36.0 kg. Other functions that are often forgotten are the social and cultural roles of sheep and their value as a means of capital accumulation and as a cash reserve to be drawn on in times of need. The order of importance of these functions varies with consumer demand in a region. In many districts of southern India and in Indonesia, for example, sheep are kept primarily for the manure they produce. In parts of Africa and especially among the Masai of Tanzania and Kenya, fat (usually from the fat-rumped Somali Blackhead and their own fat-tailed Masai sheep) is a major product as is blood for use as human food.

The situation is constantly changing. In India, for example a 'white revolution' has spread through large sections of the sheep industry. Finer wool is being produced on an ever-increasing scale. This has been seen as a surprising development as there was little demand for fine wool in these areas in the past. Indeed, a striking characteristic of many tropical sheep is that they have either a completely hairy coat or one that has only a low percentage of wool. Crossbreeding and upgrading with exotic wool breeds is now done on a large scale in South Asiaand in Lesotho which has access to the genetic resources and an outlet to the large market of South Africa (Fig. 9.1)where there are many wool-grading centres and the sheep industry continues to progress on a broad front and at a rapid pace.

In the Americas and Oceania, where there were no indigenous sheep before the arrival of the Europeans, the situation has been quite different. Wool and hair sheep have been introduced into these continents within the last 500 years and the fine wool produced by the Merino breed in tropical Australia is still of considerable importance in spite of diversification away from 'pastoralism' and often depressed world markets for natural fibres. Wool sheep are not so well established in tropical America where hair sheep, mainly of West African origin, are of much more importance as a source of meat for small farmers (Fitzhugh & Bradford, 1983).

The successful introduction of wool sheep to tropical Australia and to subtropical South Africa does suggest, however, that if there are the necessary economic incentives and technical skills wool sheep could also be introduced to the drier areas of the tropics everywhere. More productive meat and wool types might also be successfully introduced to many tropical montane areas provided the necessary conditions were made available and if existing genetic resources there were not put at too much risk of extinction.

Origins and Ancestry

Sheep belong to the tribe Caprini in the sub-family Caprinae of the family Bovidae in the

Fig. 9.1
A co-operative wool-grading centre in Lesotho, Southern Africa.

suborder Ruminantia of the order Artiodactyla. They are typical cloven-hoofed ruminants of relatively small size. The Caprini comprises five genera. Two of these, *Capra* and *Hemitragus* are true goats; one genus, *Ovis*, is the sheep; and there are two genera, *Ammotragus* and *Pseudois*, of goat-like sheep and sheep-like goats.

The Barbary sheep, or aoudad, *Ammotragus lervia* (Fig. 9.2) is confined to the Sahara and the Bharal, or blue sheep, *Pseudois nayaur* to the Himalayas: neither of these has been domesticated and neither will hybridize with true sheep of the genus *Ovis*. Fertile offspring by male Barbary sheep out of female domestic goats are, however, known.

The nomenclature of the genus *Ovis* is confused but latest opinion tends to favour six wild species. All these 'species' are fully interfertile and might therefore be considered to be monospecific. To distinguish them from the wild types, all domesticated sheep are now classed as

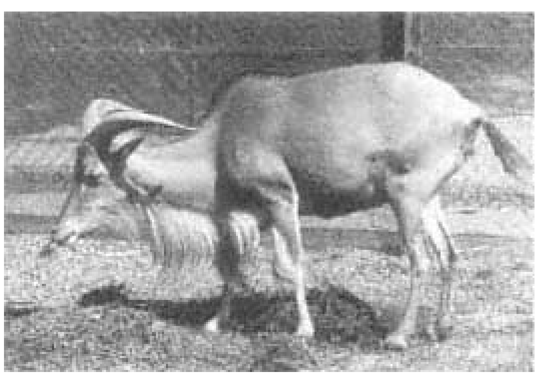


Fig. 9.2
Barbary sheep or aoudad, *Ammotragus lervia*, at
Khartoum zoo, Sudan.

Ovis aries. The mouflon (*Ovis musimon*) has the same number of chromosomes as the domestic sheep ($2n = 54$) while the urial (*Ovis orientalis*, $2n = 58$) and the argal (*Ovis poli*, $2n = 56$) differ.

The bighorn *Ovis canadensis* and the thinhorn *O. dalli* are excluded, on geographical considerations alone, from the ancestry of domestic sheep. Some authorities, on the grounds of chromosome number, consider the mouflon to be the sole ancestor of the domestic sheep. Both the argal and the urial, however, freely interbreed with, and produce fully fertile offspring from, the domestic sheep and therefore cannot be excluded from its ancestry.

Domestic goats and sheep, because of the divergence in chromosome numbers, do not usually interbreed (Gray, 1972). Experimental chimaera are known (Fehilly *et al*., 1984; Meinecke-Tillman & Meinecke, 1984) and one of these, backcrossed to a ram, is reported to have produced twin offspring (Bunch *et al*., 1976).

The most simple and effective visual way of separating goats from sheep is the carriage of the tailin all domestic forms, goats' tails are erect while those of sheep are pendent. There are, however, a considerable number of additional morphological differences between the two species. Goats have beards and caudal (i.e. at the tail) scent glands in the male. Sheep have suborbital (under the eye) tear glands and lachrymal (tear) pits in the skull and also possess foot glands: goats may, however, have glands in the forefeet. Both species differ from cattle and buffaloes in normally having only two nipples instead of four.

Domestication and Spread

Domestication of sheep possibly followed closely upon that of the goat, perhaps as long ago as 11000 BP (before present), and took place in the same area in the open forested hills of the 'fertile crescent' in Western Asia as mouflon were present in this region. The fertile crescent extended northwards from Palestine through Lebanon and across southern Turkey and then to the Zagros Mountains on the present day border of Iraq with Iran and was a major centre of the development of crop agriculture. No wild sheep were domesticated in Africa but both goats and sheep appeared in tomb and cave paintings in Egypt by about 7000 BP. Sheep probably entered sub-Saharan Africa with cattle, at some time in the period 6000-5000 BP, possibly slightly later than goats.

Archaeological evidence suggests that it was the thin-tailed hairy sheep that were first taken to Africa. It is likely that they were introduced by the same Hamitic pastoralists migrating from Western Asia who introduced the Longhorn Hamitictypified today by the N'Dama of West Africacattle to the continent. The two separate African groups of thin-tailed hairy breeds (the large semi-arid savanna type and the smaller forest type of the wetter forest region) may have developed from the same source by natural and man-assisted selection in their two widely different environments. Fat-tailed coarse-woolled sheep in Africa were probably introduced to Africa about 3000 years after the thin-tailed breeds and probably by the Isthmus of Suez at the northern end of the Red Sea and via the Babel-Mandeb Straits at its southern end. The fattailed sheep replaced thin-tailed ones in Egypt, Libya and Tunisia whereas those entering Somalia and East Africa were ultimately taken by their migratory owners to the southern tip of the African continent.

The origin of the fat-rumped breeds remains unknown but they occur in two disjunct and ecologically different regions. These regions are: Northeast and East Africa and the Indian Ocean and Red Sea littorals of the Arabian Peninsula; and Central Asia. There are, however, many differences between these fat-rumped groups. Fat-rumped sheep of SomaliArabian origin were introduced into southern South Africa during the nineteenth century and were quickly improved to form the breed known as the Blackhead Persian. This breed was extensively used in Southern and Eastern Africa for crossbreeding in spite of its low reproductive performance although it is now less popular as a crossing sheep.

Fat-tailed breeds thrive in the drier regions of northern India but farther south fat-tailed and thin-tailed wool types are gradually replaced by thin-tailed hairy breeds. The humid regions of Southeast Asia have few sheep breeds but most are small hairy types with the exception of a fat-tailed type possibly from India or Western Asia and a poor wool breed originating from crosses between the indigenous hairy type and wool sheep from Australia or South Africa. The poor coarse wool sheep of southern Thailand and Malaysia appear to have originated from crosses between woolled Chinese sheep, taken south by Thai and other peoples, and the native hairy sheep of the region.

Savanna and forest thin-tailed sheep from West Africa were taken to tropical South and Central America and the Caribbean region in the seventeenth century where they established themselves in the humid tropical regions. These were areas to which the Iberian sheep breeds introduced in the very early days of colonization of the Americas had never become acclimatized.

Sheep, perhaps more than any other domestic animal, seem particularly sensitive to changes in environmental conditions. They thrive only within 'homoclimes' but even here they have more difficulty in adjusting to changes in diet and exposure to new diseases than other farm animal species. This characteristic is so marked that in the United Kingdom hill sheep are said to be 'hefted' or acclimatized to a particular hill environment and do not accept changes of location very easily (sheep are always sold with the farm in these areas and usually account for most of the price of the total transaction). In the tropics sheep appear to thrive best in semi-arid upland areas where the vegetation is of the short grass or steppe type.

Numbers and Distribution

Sheep are more numerous in the tropics than goats, with a total population of some 500 million. They are proportionally less important than goats, however, in world numbers, accounting for somewhat less than 45% of all sheep (Table 9.1).

Africa has the largest population of tropical sheep, about 37% of all of this species in the zone being found there. The areas of concentration are similar to those for goats, these being arid and semi-arid regions of Western Africa, the Sudan, the Horn of Africa and Eastern and Southern Africa. There are far fewer sheep proportionally in South Asia than there are goats and here they represent only 14% of tropical numbers. In West Asia sheep are extremely important for meat, milk and wool and account for about 23% of the tropical population. Sheep are much more important than goats in South America as they contribute 23% to the tropical population of the species. In Eastern Asia (1 %) and Central America and the Caribbean (2%) sheep are of very minor importance.

In recent years sheep numbers have increased very slowly, by about 7% in the tropics between 1978 and 1987. The increase has been above the average in Africa (10%), less than the average in the Americas (3%) and about the average in Asia (7%). Sheep outnumber goats in the ratio 5:4 in tropical countries. With few exceptions goats are more important than sheep in humid areas (although paradoxically most goats are found in dry countries) in all the major tropical areas (Table 9.1).

Types and Breeds

Types

There has been considerable evolution towards specialized functional types in sheep in the developed countries. The major categories are wool (which is itself classed into several subtypes from fine wool to carpet wool, for example) and meat types but other important groups include dairy sheep and pelt producers.

In the tropics there are several possible typologies not related to function, including ones that take size or ear length as the major variable. The most widely used of classifications for tropical sheep, however, is based on tail type, in which four major groups are found (Fig. 9.3). Animals are thus usually assigned to long thin-tailed, short thin-tailed, fat-tailed or fat-rumped groups. The thin-tailed types are sometimes further segregated into hairy or woolled types (Epstein, 1971). Thin-tailed sheep are commonest in the northern dry tropics of Africa where they are

Table 9.1 Numbers, density and ratio to humans of sheep and ratios of sheep to goats in some selected areas and countries. (*Source*: Adapted from FAO, 1995a.)

Continent/country	Number (000)	Density (No. /km2)a	No./personb	Ratio goats : sheep
Africa	208 845	7.047	0.506	1.19
Botswana	344	0.607	0.398	0.14
Burundi	350	13.629	0.062	0.41
Congo	111	0.322	0.078	0.36
Ethiopia	21 700	21.700	n.a.	1.30
Kenya	5 500	9.664	0.267	0.74
Mozambique	119	0.152	0.095	0.31
Niger	3 700	2.921	0.490	0.63
Nigeria	14 455	15.871	0.210	0.57
Somalia	13 000	20.842	2.098	1.08
Togo	1 250	22.982	0.458	0.61
Zaire	1 012	0.446	0.037	0.23
Asia	340 102	12.695	0.185	0.91
Bangladesh	1 070	8.220	0.014	0.04
India	44 809	15.071	0.079	0.38
Indonesia	6 411	3.54	0.081	0.52
Laos	n.a.	n.a.	n.a.	n.a.
Pakistan	28 975	37.587	0.416	0.70
Philippines	30	0.101	0.001	0.01
Sri Lanka	19	0.293	0.002	0.04
Syria	12 000	65.295	3.880	10.00
Yemen	3 715	7.036	0.500	1.15
South America	94 054	5.366	1.398	4.12
Bolivia	7 789	7.183	2.735	5.13
Brazil	20 500	2.424	0.587	1.68
Ecuador	1 728	6.242	0.560	5.01
Peru	11 600	9.063	1.439	6.77

Venezuela	5500.624	0.285	0.30
World	1 086 6619.897	0.445	1.78

n.a. = not available.
a Area used to calculate density is total land area.
b Figure used to calculate ratio to people is total agricultural population.

usually of large size, or in the western humid zones of Africa where they are smaller and often referred to as dwarf or forest sheep: smaller thin-tailed sheep predominate in parts of South and Southeast Asia. Fat-tailed types predominate in Eastern Africa as far south as Mozambique, are the commonest type in North Africa and are well represented in West Asia. Fat-rumped types have some relict populations in the Arabian Peninsula but are commonest in traditional systems in Northeast Africa, although they have also spread to commercial systems in Zimbabwe and other countries of the Southern Africa region.

In Western Africa there is a clear dichotomy of types (Fitzhugh & Bradford, 1983). Large, long-legged sheep are found in the dry zones of the Sahel and smaller types with shorter legs in the coastal humid zones and their hinterlands: each type has other distinct morphological features (Table 9.2). Hair sheep in the tropical areas of America are mainly descended from thin-

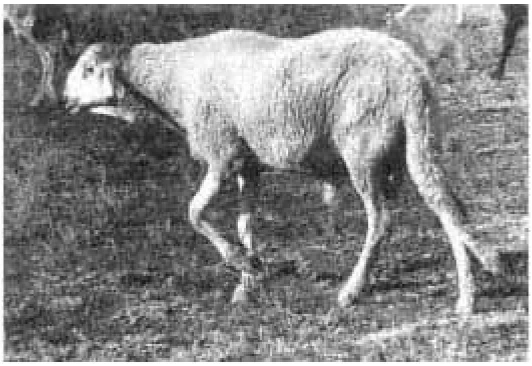
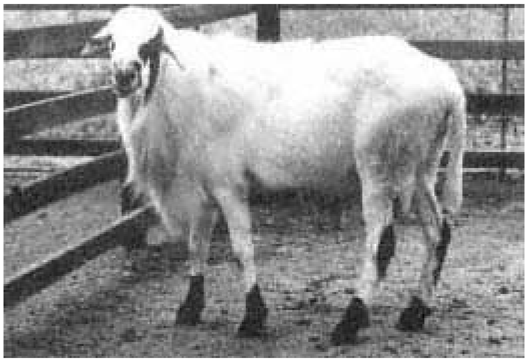


Fig. 9.3
Tail types in tropical sheep: long thin tail of Shugor subtype of Sudan Desert

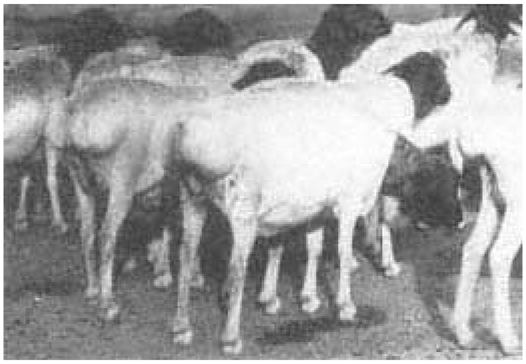


Short thin tail of Djallonké in Côte d'Ivoire

S-shaped fat tail of Afar in lowland Ethiopia

Long fat tail of RwandaBurundi

Fat tail of Barbary in Tunisia



Fat rump of Blackhead Persian in Tanzania.

tailed animals taken there from Western Africa during the days of slave-trading.

A summary of the major sheep types and their regional distribution using the criteria discussed above is given in Table 9.3.

Breeds.

There are at least 900 named breeds of sheep in the world, giving this species the distinction of having the greatest number of breeds of all

Table 9.2 Physical characteristics of African dry- and humid-adapted sheep and of American sheep. (*Source*: adapted from Fitzhugh & Bradford, 1983.)

Character	Sheep type (origin)		
	Africa dry	Africa humid	Americas
Adult female weight (kg)	>35	Forest: 2030 Savanna: 3040	3040
Adult female withers height (cm)	>60	Forest: 4055 Savanna: 5565	
Ear type	Long, pendulous	Short, horizontal	Short, horizontal
Toggles	Relatively common	Rare	
Horns			
Males	Usually present; long and spiralling	Often absent; if present, crescent shaped and short	Usually absent
Females	Usually absent	Normally absent	Normally absent
Tail	Long, extending below hocks	Short, above hocks	Medium, to hocks or shorter
Mane/apron in males	Absent	Usually present	Present (except in Brazil)
Colour	Normally white, sometimes pied	Varied colours, many mixed	Often fawn
Disease resistance	Not trypanotolerant	Trypanotolerant	

domestic animals. Most named breeds are found in Europe but in the tropics Asia has 226 breeds, Africa has 73 and Latin America and the Caribbean have 23. It is obviously not possible to describe or even list other than a few important tropical breeds (Table 9.4). Readers requiring further information should consult any of the standard texts (e.g. Mason, 1980; Acharya, 1982; Devendra & McLeroy, 1982; Fitzhugh & Bradford, 1983; Ryder, 1983; Hasnain, 1985; Wilson, 1991).

Major sheep breeds in Africa in terms of area of distribution, numbers, importance for crossbreeding or for particular traits include the Djallonké, Sudan Desert, Blackhead Persian and Masai.

The *Djallonké* is a small sheep of the West African humid zones particularly noted for its tolerance of trypanosomosis. It is found under various synonyms (including West African Dwarf, Cameroun Grassland, Guinea, Ghana Forest) in at least 18 countries although in some of the southern ones including Congo, Gabon and the Democratic Republic of Congo it is an introduction. The hair coat is usually black and white with the former often confined to the head and forequarters although other colours also occur. Adult males are usually horned and most have a mane and an apron of long hair down the throat and on the brisket. The ears are short and held horizontally and the thin tail, up to 25 cm long, reaches to the hocks. Adult males stand about 55 cm at the withers and weigh about 3035 kg, adult females are slightly smaller and weigh 2530 kg. A great deal of breeding work has been done, especially in Côte d'Ivoire, to increase the size of this rather prolific sheep which is almost entirely used for meat production. The Ivoirean strain is used in neighbouring countries, especially Ghana, Togo and Guinea on local types.

The *Sudan Desert*, also known as the Arab or Northern Sudanese, is the most important breed in Sudan and also spreads eastward to Eritrea and westward into Chad. There are many subtypes including Kababish, Meidob, Butana, Gezira, Beja, Watish, Shugor and Dubasi which not only differ in colour from the predominantly

Table 9.3 A classification of major sheep types by their region of distribution.

Region and coat type	Tail type	Representative breeds
Africa		
Hairy	Thin-tailed, forest type	Djallonké (many synonyms, West Africa); Nilotic (southern Sudan)
	Thin-tailed, savanna type	Tuareg, Maure, Fulani, Yankasa (West Africa); Zaghawa (Sudan); Hamele (Eritrea); Horro (Ethiopia)
	Fat-tailed	Sudan Desert, Dongola (Sudan); Reshidi (Eritrea); East African Blackhead (Uganda and Tanzania); Mondombes (Angola); Nguni (Southern Africa)
Woolled	Thin-tailed	Arab (Morocco and Algeria); Berber (North Africa); Arit (Ethiopia); Macina (Mali)
	Fat-tailed	Acele Guzai, Menz, Arsi (Ethiopia); Masai, Nandi, Kikuyu (East Africa); Sabi (Zimbabwe); Tswana (Botswana); Ronderib Afrikaner (South Africa); Madagascar
	Fat-rumped	Adal or Adali (Ethiopia); Blackhead Somali (Ethiopia, Somalia and Kenya); Turkana (or Gabra or Boran, Kenya); Toposa (Sudan)
Americas		
Hairy	Thin-tailed[a]	Barbados Blackbelly; Virgin Islands White; Bahama Native; Pelibuey (Cuba); Tabasco (Mexico); Roja Africana (Colombia); Morada Nova, Santa Inês (Brazil)
	Fat-tailed	Somali Brasileira[b]
Woolled	Thin-tailed	Criollo (Venezuela)
Western Asia		
Hairy	Thin-tailed	Najdi (or Bedouin or Arabian Long-tailed, Saudi Arabia and Iraq)
	Fat-tailed	Radmani (Yemen)
Woolled	Thin-tailed	Zel (Iran)
	Fat-tailed	Awassi (several types and synonyms, widespread); Arabi (Jordan and Iraq); Baluchi (Iran and Pakistan)
South Asia (Indian sub-continent and islands)		
Hairy	Thin-tailed	Bellari, Bonpala, Chottanagpuri, Coimbatore, Deccani, Ganjam, Kenguri, Kilakarsal, Madras Red, Mandya, Mecheri, Nellore, Rhamnad White, Shahabadi, Tirarchy Black, Vembur (India); Jaffna (Sri Lanka)
Woolled	Thin-tailed	Chokla, Nali, Marwari, Magra (or Bikaneri), Jaisalmeri (or Lohi), Pugal, Malpura (or Desi), Sonadi, Patanwadi, Muzzafornagri, Jalauni, Hassan, Nilgiri, Hissardale (= Mogra × Merino) (India)
Southeast Asia		
Woolled	Thin-tailed	Javanese of Madurese (Indonesia); Malaysan or Kelantan (Malaysia); Thai (Thailand)
	Fat-tailed	Priangan (composite or Merino, Cape and Javanese), East Javanese or Donggala (Indonesia)

a With the exception of the Santa Inês all probably originate from forest thin-tailed African

sheep.
b This and similar types derive from relatively recent Blackhead Persian imports from South Africa.

Table 9.4 Some major sheep breeds and production functions in the tropics.

Country/area	Breed name(s)	Production function(s)
India	Lohi, Mandya, Nellore Bellari, Chokla, Jaisalmeri, Marwari, Malpura	Meat (Nellore also produces hair) Carpet wool
Pakistan	Baluchi	Meat
Nepal	Bhanglung, Baruwal, Kagi, Lampuchre	Meat, coarse wool
Indonesia	Javanese Thin-tailed, East Java Fat-tailed. Priangan	Prolificacy, meat
Iran	Karakul, Mehraban, Baluchi (= Na'ini), Ghezel, Bakhtiari	Pelts, carpet wool, meat, milk
Sri Lanka	Jaffna	Hair
Malaysia	Indigenous	Carpet wool
Cyprus	Chios	Milk, prolificacy
Near East	Awassi	Milk, coarse wool
Saudi Arabia	Najdi, Hejazi	Meat, coarse wool, milk
Yemen	Radmani (= Sha'ara)	Milk, meat
Egypt	Barki, Ossimi	Coarse wool, meat
Maghreb	Barbary [fat-tail], Arab (several local types Doukkala, Zemmour, Sidi Aissa), Berber [thin-tail] (several local typesTadla, Beni Gouil)	Meat, coarse wool
Morocco	D'man, Sardi	Prolificacy, coarse wool
African Sahel	Sudan Desert (several local typesShugor Dubasi, Watish), Sahel (several local typesTouabire, Toronké, Touareg), Black Maure/Zaghawa	Meat, milk, hair (Maure)
African humid/ sub-humid zones	Djallonké (several local typesKirdi, Ghana Forest, Poulfouli, Cameroun Grassland). Mossi	Meat (skin eaten with meat)
Nigeria	Uda, Balami, Yankasa	Meat
Mali	Macina	Coarse wool, meat
Ethiopia	Afar (= Adal), Highland (several local types Menz, Bonga, Horro, Welo, Arusi)	Coarse wool, meat
East Africa	Masai, East African Blackhead, Rwanda	Meat, fat
Southern Africa	Tswana, Swazi, Landim, Sabi, Blackhead Persian (several derivativesDorper, Van Rooey, Ronderib Afrikaner)	Meat
Caribbean and Central	Barbados Blackbelly, Virgin Islands White, Pelibuey, Roja Africana, Criollo	Meat, prolificacy

America		
Brazil	Morada Nova, Santa Inês, Brazilian Somali	Meat
Peru	Junin	Medium/coarse wool, meat

sandy red but also in production characters (Sulieman & Wilson, 1990). The best sheep are said to be owned by the camel-owning tribes of northern Kordofan in the west of the country. This is a very large long-legged sheep with a very long fat tail that trails on the ground in some subtypes. The ears are long and pendent. Horns may be present in males but are usually absent in females. Mature rams may stand 90 cm at the shoulder and weigh up to 80 kg. These sheep are kept for both meat and milk and produce good quality skins.

The *Blackhead Persian* is a large fat-rumped breed developed in South Africa from Somalitype sheep imported in 1870 (Joubert, 1969). Two types are distinguished in South Africa, one with a long coarse woolly coat and rams that are usually horned, and one with a smooth kempy coat that is usually polled. As the name implies the head (and part of the neck) is black with the remainder of the colour being white. The small head carries short pointed ears. The dewlap is well developed and the short legs support a solid blocky body. The rudimentary tail on the end of the fat rumpwhich may weigh up to 11 kgis only about 5 cm long. These sheep are extremely well adapted to very dry conditions but one penalty that is paid is the very small litter size and twin births are very rare. The breed has been used much in the past to modify other breeds in Africa and elsewhere. One of the most successful of the Blackhead Persian derivatives is the Dorper (Fig. 9.4), developed in South Africa from crosses with the Dorset Horn. The Dorper, which is now popular in Southern Africa and Kenya, retains much of the hardiness of the Blackhead Persian but is more prolific, grows faster and has much better carcase composition with fat more evenly spread over the body. The Wiltiperbred in Zimbabwe from the Blackhead Persian and the Wiltshire Horn (the only non-woolled sheep native to the United Kingdom)is not so popular; other derived breeds include the Van Rooy and the Benzuidenhout Africander.

The *Masai* sheep of northern Tanzania and southern Kenya is a fat-tailed coarse-woolled or hairy type that is typical of many similar strains found in Eastern, Northeast and parts of Central Africa as far south as Botswana. These are relatively long-legged animals, predominantly red or red and white in colour, horned or hornless and have medium length semi-pendent ears although vestigial ears (due to a recessive gene) are not uncommon. This is mainly a meat-type sheep with males weighing 3540 kg and standing as high as 75 cm at the withers. Some Masai subtypes exhibit strong resistance or tolerance of

Fig. 9.4
Some major sheep breeds of the tropics and subtropics: Dorper on sparse grazing in Botswana

An Awassi flock in Jordan

Kagi sheep in the Middle Hills of Nepal

Santa Inês sheep at the National Sheep Production
Station, Sobral in Brazil.

internal parasites, especially to *Haemonchus contortus* (Baker, 1995), and exhibit the phenomenon known as self-cure.

Sheep breeds of West Asia and North Africa (Osman, 1986) are very varied in tail type and amount and character of wool (Table 9.5). In Iran common fat-tailed breeds are Karakul, Baluchi (also known as Naeini) and Mehraban; the first two are found in nomadic systems and receive little or no supplementation whereas the third is more intensively managed. The Karakul and the Mehraban are larger than the Baluchi. Dressing percentage of all three is about 48 of which 3% is tail.

The *Awassi* (Fig. 9.4) was originally a native multi-purpose (wool, meat, milk) fat-tailed and coarse-woolled breed of the nomadic Bedu in West Asia. It is now found in traditional and modern production systems in Iraq, Syria, Jordan, Lebanon, Saudi Arabia (where it is known as the Na'aimi), Iran, Turkey, Cyprus and Israel. In the basic breed males are horned but females are polled and the body colour is usually white with a dark red or brown head. The ears are long and pendulous. Mature males are up to 75 cm at the withers and weigh 50 kg or more. The Awassi has now been developed into a number of strains or even breeds, some of which maintain their multi-purpose characteristics, others of which are more specialized. In Israel the breed has been particularly developed for milk production with some individuals having lactation yields of 350 kg (Epstein, 1977).

Major sheep breeds in India include the Deccani and Marwari. The thin-tailed *Deccani* is widespread in Maharashtra, Andhra Pradesh and Karnataka States. The hair/coarse wool coat is usually black in colour or black with white markings. Rams are horned, measure 6569 cm at the withers and weigh 3640 kg. The *Marwari* is another of the many sheep breeds of India with thin tails and coarse wool that resemble the Blackhead Persian in colour. It is polled and has small tubular ears and is not as tall or heavy as the Deccani, being only 60 cm at the withers and weighing about 30 kg. The Bhanglung, Baruwal, Kagi (Fig. 9.4) and Lampuchre are small thintailed breeds of Nepal that are used for wool and meat and for transport purposes (Wilson, 1997).

Sumatran sheep under rubber in Indonesia weigh 22 kg and produce 1.54 lambs at intervals of 201 days and show exceptional potential for accelerated lambing in integrated plantation systems in the humid tropics. Other Indonesian sheep include the Javanese or Madurese which are medium-sized and thin-tailed and carry a

Table 9.5 Functional and morphological classification of some indigenous sheep breeds of Northern Africa and Western Asia. (*Source*: Osman, 1986.)

Fleece type	Tail type, breed and location		
	Thin	Fat	Fat-rumped
Short hair	Sudan Desert (northern Sudan), Nilotic (southern Sudan)	Hejazi (western Saudi Arabia)	Blackhead Somali (Somalia), Toposa (southern Sudan), Local (Bahrein)
Long hair	Zaghawa (western Sudan)	Najdi (Saudi Arabia)	
Coarse wool	Kurassi (southern Egypt), Dongola (northern Sudan), Omani (Oman)	Barbary (Tunisia), Barki (western Egypt), Ossimi, Rahmani (lower Egypt), Awassi (Syria, Jordan, Iraq, Lebanon, Israel), Arab (southern Iraq), Kurdi (northern Iraq)	
Medium wool	Thibar (Tunisia)		

hairy/wool coat which is not made use of locally. Coat colour is white with black spots and ears are of medium length and carried horizontally. Rams have closely coiled horns but ewes are normally polled. Mature males measure 60 cm at the shoulder and weigh 4060 kg.

Hair sheep in Brazil belong to the thin-tailed, fat-tailed or fat-rumped types. The Santa Inês (Fig. 9.4) and Morada Nova belong to the first group. The *Santa Inês* is a large, fertile and prolific breed and is probably descended from crossing the large (8090 kg ram weight) coarse-woolled Italian Bergamasca breed with African hair sheep. The Santa Inês has been selected for size and lack of wool and there is a breed standard which includes the animal being polled, having a medium length thin tail, heavy bone and black or white hooves. The *Morada Nova* is also thin-tailed and is possibly descended from the Portuguese medium wool Bordaleiro with large infusions of West African blood: the breed standard includes red colour (although white is also accepted) with a white tail tip and black hooves, no horns, pointed shell-shaped ears 9 cm in length, long head with subconvex profile, short and slightly sloping rump, thin tail, dark skin and mucous membranes, and short hair that is shiny and thick. The Morada is dual-purpose for meat and leather. The fat-rumped Brazilian Somali is relatively new to the country, being first imported in 1939. This fat-rumped sheep or 'rabo largo' is apparently descended mainly from South African sheep, is partially woolled, has horns, and is white, spotted or white with a spotted head.

More than 50% of the 15 million sheep in Peru are kept by small farmers or peasants and are considered to be of the Criollo breed (Burfening & Chavez, 1996). The *Criollo* has a typically pear-shaped body with a small head and is usually horned. These sheep, unlike those on modern larger operations, are probably not descended from Spanish Merino but from the coarse-woolled Latxa and Churra types of Castille in northern Spain. Productive characteristics vary greatly and seem to depend mainly on location. Although not as productive in conventional terms such as weaning weight or fleece weight as 'improved' breeds they, and their crosses with these improved breeds, have higher survival rates than pure breeds of the latter type and thus show good adaptation to their environment.

Many other sheep in South American countries are also known as Criollo. Those developed in Venezuela, for example, probably do have original Merino blood. Many attempts have been made to upgrade these with Corriedale, Romney Marsh and the English Down breeds especially in highland areas where the climatic environment is favourable. In drier areas Merino and Rambouillet have been used. Breed characteristics include a spotted white fleece of long coarse wool and horns.

The *Barbados Blackbelly* is a moderately large, long-legged hairy and thin-tailed sheep originally bred on the island of Barbados in the Caribbean by crossing West African hair sheep, possibly from Cameroon and introduced during slave trading days, with a European breed, probably British or Dutch (Coombs, 1983). The coat is light to dark brown in colour with the exception of the black belly from which the breed takes its name. The hair is smooth except for the mane or ruff of the male. Mature rams weigh 6098 kg. This is a very promising breed for humid tropical conditions and has been exported to countries in tropical South America and to Fiji.

Until recently, blood grouping, chromosome mapping, DNA profiles and other types of biotechnology have hardly been used in identifying sheep breeds. There is, however, considerably increased interest in this area of research. It is certain that in the near future clearer indications will emerge on the relationships between one population of sheep and another.

Genetic Modification

Since about 1850 imports to tropical type climates of specialized types of sheep were mainly for modern commercial operations. The Republic of South Africa was perhaps foremost in this movement with Merino and Karakul sheep (and Angora goats). There are now, however, large populations of Merino sheep in Kenya and

Zimbabwe and of Karakul sheep in Namibia. Merinos are also important in Lesotho in the small-scale sector, as are Angora goats. Attempts to introduce other exotic breeds have generally been unsuccessful but the composite Dorper is used for meat production under local conditions, notably in Zimbabwe and Kenya and more recently in Botswana. Finn, Romanov and Chios sheep have been imported to Egypt in attempts to improve prolificacy in native Ossimi and Barki sheep (Aboul-Ela & Aboul-Naga, 1987) and there have been many attempts to raise milk output through crossing with East Friesian sheep among others. In areas of relatively benign climate and where good management, health care and nutrition can be assured, such attempts may be justified. Most have failed, however, for lack of these inputs, through ill-defined breeding objectives and a failure of continuity.

Adaptation

Small ruminants are less well adapted to dry environments than the one-humped camel. Homeothermy or the need to maintain a relatively stable internal body temperature is much more strictly enforced in sheep and goats than camels and neither species normally exhibits large changes in deep body temperature.

Native African hair sheep and goats can store only small amounts of heat within their normal temperature range of 36° to 38°C (Maloiy & Taylor, 1971). At higher ambient temperatures both species need to pant in order to achieve evaporative cooling and it is generally considered that heat tolerance is only possible when sufficient water is available for it to be used for evaporative cooling (Quartermain, 1964; Bligh, 1972). Some sheep in the Middle East have higher body temperatures in the range of 38.7° to 40.5°C and thus may be better adapted to desert conditions (Degen, 1977).

Sheep adapted to dry conditions often have fat deposited in one area of the body in a manner analogous to the hump of the camel. The extreme case is shown by fat-rumped sheep, notably the Blackhead Persian. In this type (cf. Fig. 9.3 (bottom right)) almost all of the fat is deposited high on the rump (the tail is very short and protrudes from this grotesque mass like a small finger), although there are also pads of fat behind the poll and there are small deposits of kidney fat. The coat is white and of short, sleek hair and reflects the short-wave radiation very efficiently. Only the head is black. The Blackhead Persian adopts the same grazing orientation as the camel and is almost always aligned with its long axis towards the sun. It has been shown in Southern Africa that the heat load in sheep placed perpendicularly to the sun is reduced to approximately half of that in animals that stand sideways to the sun183°W against 374°W at a sun elevation of 8° and 203°W against 381°W at a sun elevation of 42° (Hofmeyr & Louw, 1987). Other types of desert sheep with fat tails (as opposed to fat rumps) are widespread throughout the arid zones of East and Northeast Africa, Mediterranean Africa and the countries of West Asia. The regional distribution of fat has most likely resulted from a long period of adaptation to harsh conditions. In Sudan, for example, Desert sheep deposit more intramuscular and internal fat and less subcutaneous fat than exotic breeds (Gaili *et al*., 1972). This may be explained by the degree of heat tolerance which is associated with a low accumulation rate in the subcutaneous fat deposit. This needs to be taken into consideration when introducing exotic breeds to hot climates. Morphological characteristics such as long legs, white colour and long pendulous ears might not only be beneficial directly to the sheep but also lead indirectly to lower carcase weight loss.

Many sheep breeds have been selected by man for high wool production. The apparent paradox of the world's most famous wool breed, the Merino, doing best in the arid areas of Australia, South Africa and South America, therefore needs some explanation. The outer fleece temperature can be as high as 85°C, resulting in a reversed temperature gradient from animal to environment. The temperature at the body surface under the wool does not exceed 40°C, the wool is therefore acting as an efficient insulator by intercepting much of the short-wave radiation and scattering long-wave radiation. Australian Merino sheep shorn in summer had a water turnover rate double that of sheep in full wool (Macfarlane *et al*., 1966). Wool preserves the body temperature at night by preventing dissipation of heat from the surface zone. It is clear that wool has some advantages in hot dry climates but the reverse is the case in hot humid ones (McDowell, 1972).

Sheep respond to heat load by sweating and panting but their sweating mechanism is not very efficient and the magnitude of the response declines over time (Robertshaw, 1968). This inability of sheep to maintain a high rate of sweating has resulted in their principal cooling strategy being that of panting or respiratory heat loss. The panting rate of sheep increases by as much as 674% under a heat load (Hales & Webster, 1967) and sheep under heat stress need constant access to water unless they can adjust their behaviour sufficiently to overcome the lack of physiological adaptation.

A further adaptation to hot environments in sheep and goats relates to the scrotum. In both species the testicles may be enclosed in a long and pendulous sac. Semen quantity and quality is better in animals in which a further refinement, the splitting of the scrotal sac into two separate halves for more than one-third of its length, is present. Testes temperatures can be further reduced as a result of coiling the arteries around the scrotal veins (Waites & Moule, 1961). Behavioural adaptations are, in fact, an additional important factor in maintaining a low scrotal temperature (Brown, 1974). Merino sheep in an open paddock that were able to rest in shade during the day maintained scrotal temperatures, as well as respiration rates, much below those of animals which were forced to spend the hottest part of the day in the open (Fig. 9.5).

Livestock in developing countries are often characterized as low producers but comparisons with 'improved' types based only on direct production traits rarely take into account other factors such as inputs, production and management practices. These comparisons usually also ignore the acquired adaptive and special genetic attributes of native animal genetic resources in tropical countries, More information is now becoming available on the adaptive and special genetic attributes which are often ignored when their productivities are compared. Recent work on some of these characteristics for sheep breeds of West and Central Africa is an example of the combinations of attributes which make these animals particularly suited to their production, health, social and economic environments (Table 9.6).

Reproduction

Male

There is relatively little information on the age or stage of physical development at which rams of tropical sheep breeds reach puberty. In highland Ethiopia, however, it has been shown that rams of the Menz breed reach puberty (defined as the age when an ejaculate of semen with 50 million sperm of at least 10% motility is first collected) at 288 ± 6 days (Mukasa-Mugerwa & Ezaz,1992).

Observations in Australia, India, the United States and elsewhere indicate that rams may be more fertile in the cooler winter than during the hotter summer season. In Florida it has been stated that the management of rams in cooled rooms during hot weather improved semen quality (Loggins *et al*., 1964). Within- and between-breed differences in the reactions of rams to high environmental temperatures have been observed. It has been shown in Australia, for example, that Merino rams with a large number of skin folds are less fertile under hot conditions than those with fewer folds. In Florida the fertility of rams of the local Florida breed is not affected to the same extent during the hot summer months as is that of Hampshire and Rambouillet rams. In Australia it has been shown that the semen quality of Dorset Horns was less affected by high environmental temperatures than that of Merino and Border Leicester rams (Lindsay, 1969). Merino rams, on the other hand, maintained sexual activity at higher experimental temperatures than did the Dorset Horn and Border Leicester.

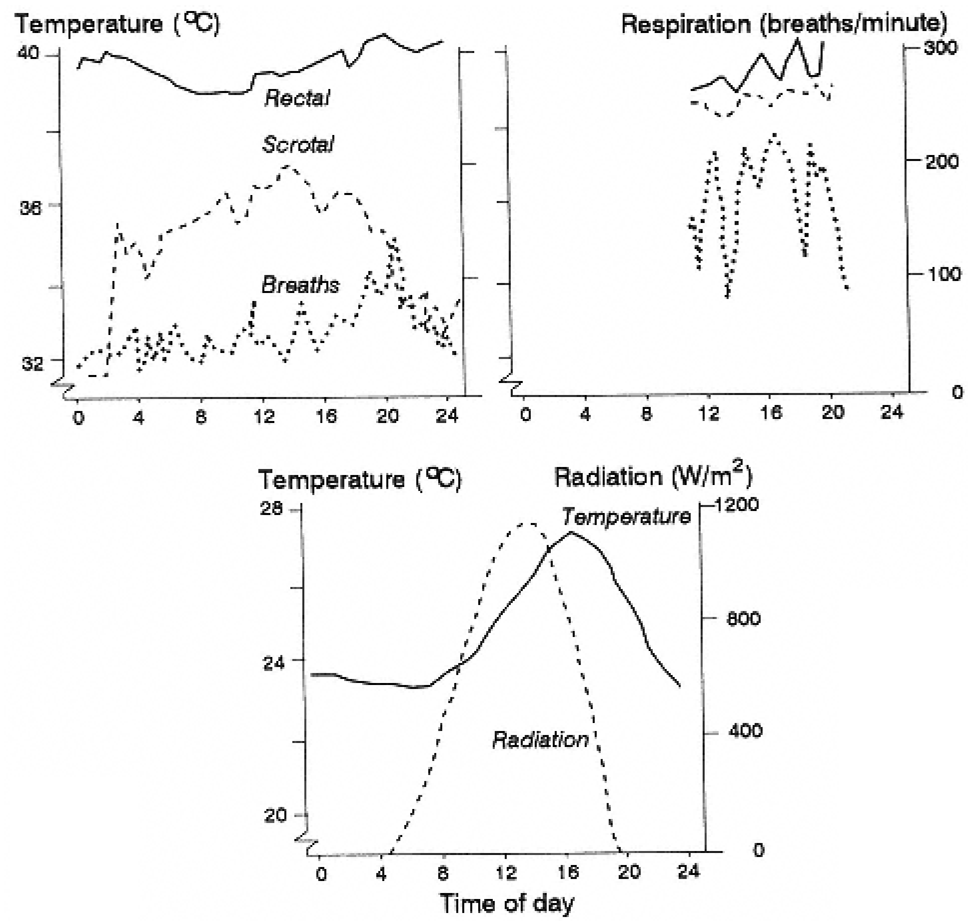


Fig. 9.5
Rectal and subcutaneous scrotal temperatures and respiration rates of free ranging (top left) and restrained (top right) Merino rams in relation to environmental conditions (bottom) in New South Wales.
(Source: adapted from Brown, 1974.)

Decrease in the quality of semen from rams subjected to high environmental temperatures appears to be related to a rise in temperature in the subcutaneous tissue of the scrotum. This must be related to an increase in body temperature caused by general heat stress. Thus the efficiency of the heat dissipating mechanism of the scrotum will have some effect on determining the quality of the semen when the animal is subject to high environmental temperatures. A low sperm count and a high incidence of abnormal sperm in semen are characteristic and the results of experimental work in Australia suggest that the major effects occur during spermatogenesis and not during storage. The testes of rams subject to heat stress become soft and flabby and sexual activity is affected with rams mounting less and showing a slower reaction time (Thwaites, 1985).

In addition to temperature other climatic factors may reduce sperm quality. In the former USSR, for example, low atmospheric pressure reduced sperm quality (Malikov, 1963)this may be of practical importance in some tropical mountainous areas.

Little is known of the reactions of rams of tropical breeds to high environmental temperatures. It may be surmised that one of the reasons for lambing being seasonal in the tropics, despite the fact that ewes do not have a close breeding

Table 9.6 Summary of adaptive and special attributes of West and Central African sheep genetic resources. (*Source*: Yapi-Gnaoré *et al*., in press.)

Types/Breeds	Resistance/tolerance to diseases/parasites	Adaptation to environment	Other special attributes
Dwarf	Trypanosomosis		Year-round reproduction
Djallonké	Trypanosomosis, endoparasites, foot-and- mouth disease, sore-mouth, blue-tongue, tick-borne diseases (Cowdriosis, anaplasmosis, piroplasmosis), mange, *Linognathus ovillus*	Hot and humid conditions, limited and irregular feed supply	Vigorous, minimal management needed, early sexual maturity, year-round reproduction, efficient urea recycling
Kirdi, Mayo-Kebbi	Gastrointestinal nematodes		
West African Long-legged	Blue-tongue, Parainfluenza type 3, helminth parasites		Self-cure of gastrointestinal nematodes
Uda, Bali-Bali			Tolerance of long watering interval, travel long distance, year-round reproduction, best stall-fed breed (Bali-Bali), calm temperament (Bali-Bali)
Balami	Ife virus		Year-round reproduction, favoured stall-fed breed
Peul, Peul-Peul	*Pasteurella haemolytica, P. multicida, Mycoplasma arginini*		Year-round reproduction,
Yankasa			Tolerance of long watering interval
Black Maure, Touabire, Arab		Dry and hot conditions	Long distance travel, use of poor pasture
Touareg, Ara-Ara		Dry and hot conditions	Long distance travel
Coarse wool			
Macina, Koundoum		Flooded and humid areas	Only wool producing sheep of Sahel region

season, is because rams are less fertile at some seasons than others. The libido of Baggara rams in Sudan does not, however, appear to be affected by season (Wilson, 1976). There is certainly reason to suggest that when crossbreeding and/or upgrading are contemplated and exotic rams are imported, every effort should be made to ameliorate climatic conditions for them and to breed in the first place during the cooler season.

Rams imported into the tropics from the temperate zone appear to be less fertile or even sterile for up to 1 year after importation (Moule, 1970). This effect is distinct from any climatic stress. It is presumably related to photoperiod and initiated by transfer from an environment with a changing daylength to one in which there is little change.

Mating Behaviour

It is possible for a ram to serve up to 60 ewes in one breeding season but it is normal practice in the temperate zone to mate one ram with up to 40 ewes. In the tropics where all year round breeding is practised, where under extensive husbandry conditions the ewes may be very dispersed and where both rams and ewes may be undernourished the number of ewes per ram must usually be severely curtailed. In India it has often been the practice to use one ram per six ewes, in Africa one ram per 10 ewes and in Western Asia one ram per 20 ewes.

With these male:female ratios it is clear that ram mating performance and fertility are of far greater importance than individual ewe fertility. There are often seasonal differences in fertility and libido of rams which may need to be taken into account when using planned mating programmes. Ram fertility and sexual activity are influenced by liveweight so rams should be in good condition when put to the ewes. Rams of tropical breeds can, however, have very good performances. The Horro breed in Ethiopia, for example, is highly fertile and individual rams usually achieve an 8291% conception rate in ewes they mate, with more than 60% of ewes conceiving in the first cycle (Gizaw & Thwaites, 1997), but even here it can be seen that at least two rams should be used in a flock.

Female

In the temperate zone some sheep may reach sexual maturity at 47 months and first oestrus may occur in ewe lambs of the mutton breeds at 810 months. Tropical breeds do not seem to differ from this. In Venezuela, for example, West African sheep have their first oestrus at 286 ± 41.3 (range 190420) days (Stagnaro, 1983) and in Brazil age at first oestrus of the Morada Nova and Santa Inês breeds is 214.5 and 219.7 days respectively (de Figueiredo *et al*., 1983). Where tropical sheep appear to mature later it is probable that the difference is not genetic but related to poor nutrition, less than optimal health status and the generally lax management that prevails in many tropical systems. Stressful climatic conditions may also have some influence on sexual maturity.

The oestrous cycle appears to be of similar length in both temperate and tropical sheep. In Awassi sheep, for example, the average cycle length has been reported as 18 (range 1621) days (Amir & Volcani, 1965). In Djallonké sheep it is 17.4 (1619) days (Berger, 1983). West African sheep in Venezuela have a cycle length of 17.1 ± 3.1 (432) days (Stagnaro, 1983). In Brazil the cycle length is 16.1 ± 1.1 days in the Morada Nova breed and 19.6 ± 7.5 days in the Santa Inês (de Figueiredo *et al*., 1983). The average duration of oestrus of 1824 hours seems to be the same in both tropical and temperate sheep but may be as long as 36 hours in the Djallonké (Berger, 1983). In West African sheep in Venezuela oestrus lasts 26.7 ± 9.2 hours (Stagnaro, 1983). The Morada Nova has an oestrus duration of 30.4 ± 13.9 days whereas that of the Santa Inês breed is 25.8 ± 7.1 hours (de Figueiredo *et al*., 1983). There is no information on the time of ovulation after the onset of oestrus in tropical sheep.

Onset of oestrus in the temperate zone is initiated by changes in daylength so that in the northern hemisphere the breeding season usually occurs during autumn when days are becoming shorter. In the tropics there are no major changes in daylength and ewes could theoretically come into heat at any time of year. This does, in fact, happen in practice. In some areas, and especially where there is little seasonal variation in rainfall (and therefore in nutritional status), for example in Cameroon (Vallerand & Branckaert, 1975), there may be the same percentage of births in every month of the year. In drier tropical areas, however, although births do take place all year round there is often seasonal variation in the number of births (Wilson, 1976; Wilson *et al*., 1984; Wilson & Light, 1986) that is almost certainly related to nutritional status at the time of conception.

An interesting experiment in Australia (Thwaites, 1965) looked at the effects of daylight on the breeding season. One group was exposed to natural daylight (at 30°30'S), seasonal lighting was reversed in a second group and a third group was exposed to equatorial lighting conditions of equal day and night. Under natural lighting conditions the ewes showed a restricted breeding season that averaged 102.5 days during the autumn and winter months. Within the season these ewes averaged 7.14 ± 0.47 oestrous periods. In the second group the breeding season was reversed. There were some daylength-ambient temperature interactions with low temperatures tending to stimulate and high temperatures tending to inhibit the manifestation of oestrus. Under equatorial lighting the normal pattern of seasonal breeding was lost after 1 year so that oestrus occurred in any month, although the intensity of breeding was reduced. These experimental results are of the greatest practical importance when the possibilities for breeding sheep in the tropics are considered. It has been known for a long time that when temperate-type sheep are transferred from the temperate zone to the tropics they may produce lambs during any month of the year but that their overall lambing percentage is often low. All indigenous tropical sheep can breed at any season of the year although their lambing percentages appear to be influenced by seasonal factors. Bikaneri ewes bred in the spring, autumn and rainy seasons in Uttar Pradesh in India, for example, had lambing percentages of 66.6, 74.4 and 72.2 with winter-born lambs being heavier at birth and at all stages to 9 months of age than lambs born in the spring or rainy season (Saraswat *et al*., 1968).

From practical observations and experimental evidence it can be concluded that it might be possible to obtain two crops of lambs each year and quite definitely it should be possible to obtain three crops in 2 years. In many cases, however, the breeding season must be carefully chosen to take account of the effect of factors other than daylight length on reproductive behaviour. Consideration also needs to be given to the environmental and feed conditions the ewe and lamb will encounter at the birth of the latter.

High ambient temperature in climatic chambers have a profound effect on the reproductive behaviour of ewes (Ryle, 1961); the number of ovulations is slightly reduced, the development of potential embryos is decreased, embryonic mortality is increased and the birth weight of surviving fetuses is lowered. The effect of an ambient temperature of 32.2°C at breeding and 1, 3 and 5 days later increased the percentage of morphologically abnormal ova from 3.7 in the control to 30.8 in the 0 and 1-day treated groups (Dutt, 1963). Embryonic loss was significantly higher in the treated groups and ranged from 61.5 to 100%. The most interesting fact emerging from this experiment is that embryonic loss is significantly higher at the time of breeding and 1 day later than it is at 3 and 5 days later, suggesting that the sheep zygote is most sensitive to the effect of high body temperature during the initial stage of cleavage while it is still in the oviduct.

It is probable that the same effects occur under field conditions in the tropics. Their incidence may be mitigated, however, by diurnal and seasonal fluctuations in temperature and be complicated by interactions with the photoperiodic effect of daylength. This occurs even in the temperate zone. In the United Kingdom, for example, higher than normal ambient temperatures delay the onset of the autumn breeding season.

Field data from Australia and elsewhere (Thwaites, 1985) suggest that high ambient temperatures reduce lambing percentages, decrease the incidence of twinning and decrease the birth weight and viability of lambs. In Lebanon, for example, the incidence of twin births in Awassi sheep was 7.1% for spring mated ewes, 9.5% for those mated in summer and 24.5% for those mated in autumn (Ampy & Rottensten, 1968). In Mali most births took place in September to December but litter sizes were greatest in March and April related to conceptions in the later part of the rainy season when nutritional status was high (Wilson & Light, 1986).

Putting the ewe on a high plane of nutrition just before the start of the breeding season is a common practice in the temperate zone where it is known as 'flushing'. This triggers off the shedding of more eggs by the female and results in an increase in twin births. The same phenomenon occurs in tropical sheep. Another practice to bring ewes into heat and induce them to shed more eggs over a short time period is the use of vasectomized rams. This technique, sometimes known as the 'ram effect' and with either vasectomized or entire rams has been used with success in many tropical areas (Lahlou-Kassi & Boukhliq, 1989).

Reproductive Performance

Age at First Lambing

Under natural conditions of free mating tropical sheep would give birth to their first lambs at about 1416 months of age. This does in fact seem to be the general case in traditional systems of management where there is no stratification of flocks and rams run with ewes on a year-round basis (Table 9.7). This 'natural' system is often interfered with under modern management practices where artificial restrictions on breeding, such as not putting ewe lambs to the ram until they reach a certain weight or only at certain times of the year, may be imposed. This has the practical effect of retarding the age at first lambing and may have repercussions on a reduced total life-time performance. Under Mozambique research station conditions, for example, the average age at which sheep first lambed (Table 9.7) over a 7-year period was 773 ± 302 days (Rocha *et al*., 1990). The situation may also arise in traditional systems where

Table 9.7 Major reproductive parameters of sheep in the tropics and subtropics.

Breed	Country	Reproductive parameter			Source
		Age at first lambing (months)	Lambing interval (days)	Litter size (No. of lambs)	
Djallonké	Cameroon	16.3	191		
	Côte d'Ivoire	11.5	208294		Vallerand & Branckaert, 1975 Rombaut & van Vlandaeren, 1976
Masai	Kenya	18.0	305		Wilson *et al*., 1984
Baqqara	Sudan		275		Wilson, 1976
Sudan Desert/Shugor	Sudan		449	1.30	Sulieman & Wilson, 1990
Sudan Desert/Dubasi	Sudan		425	1.18	Sulieman & Wilson, 1990
Sudan Desert/Watish	Sudan		403	1.17	Sulieman & Wilson, 1990
Landim	Mozambique	25.4	398	1.48	Rocha *et al*., 1990
Awassi	Western Asia	1820			Devendra & McLeroy, 1982
Awassi	Syria	24	12	1.05	quoted in Aboul-Ela & Aboul- Naga, 1987
Ossimi	Egypt	1520		1.17	quoted in Aboul-Ela & Aboul- Naga, 1987
Najdi	Saudi Arabia	1318		1.101.38	quoted in Aboul-Ela & Aboul- Naga, 1987
Karakul	Iran		78		quoted in Aboul-Ela & Aboul- Naga, 1987
Chios	Cyprus	>13	612	2.3	Mason, 1980
D'man	Morocco	1214	68	1.982.67	quoted in Aboul-Ela & Aboul- Naga, 1987
Javanese	Indonesia	612	69	1.6	Mason, 1980

Bibrik	Pakistan			1.001.05	Osman, 1986
Marwari	India	18.0			Acharya, 1982
Barbados Blackbelly	Barbados	16.0	158520		Bradford *et al*., 1983
Barbados Blackbelly	Mexico			1.67	Segura *et al*., 1996
Pelibuey	Mexico			1.23	Segura *et al*., 1996
West African	Venezuela			1.141.77	Stagnaro, 1983
Morada Nova	Brazil	16.3		1.67	de Figueiredo *et al*., 1983
Santa Inês	Brazil	14.8		1.67	de Figueiredo *et al*., 1983

breeding is restricted for other purposes. This is the case in the Masai system in southern Kenya where rams are fitted with an apron to prevent indiscriminate mating and in which the age at first lambing is about 550 days or 18 months (Wilson *et al*., 1984).

Lambing Interval.

As indicated under the section on physiology three lambings in 2 years are easily attainable by most tropical sheep and this level of performance is achieved in most traditional systems (Table 9.7). In Sudan, for example, Baqqara sheep in the western savanna area had a lambing interval of 257.2 ± 58.6 (range 159420) days although there was a peak in conceptions during the rainy season when nutrient intake was high (Wilson, 1976). In Barbados a commercial flock of Blackbelly sheep had a mean lambing interval of 244 (158520 days) with lambs born throughout the year (Bradford *et al*., 1983). In modern systems which aim at a single lambing per year, the overall result is usually an average lambing interval in excess of 1 year as it is rare for all ewes to conceive in the short breeding season that is usually allowed. The Mozambique research station serves as an example once again where the overall parturition interval was 398 ± 164 days (Rocha *et al*., 1990).

Litter Size

Litter sizes are related to breed (Fig. 9.6) and several other factors including age of the ewe (Fig. 9.7) and the season of birth or conception. Litter sizes at birth of Pelibuey ewes in Yucatan of 1.23 were much smaller than the 1.67 of Barbados Blackbelly ewes kept under exactly the same management conditions (Segura *et al*., 1996). Litter sizes in both breeds increased with increasing parity up to and beyond the fifth lambing. More young per parturition were also born to ewes that were heavier than the mean than to those that were lighter. Blackbelly ewes produced 43.1, 46.5, 8.4 and 2.0% of single, twin, triplet and quadruplet births whereas the corre-

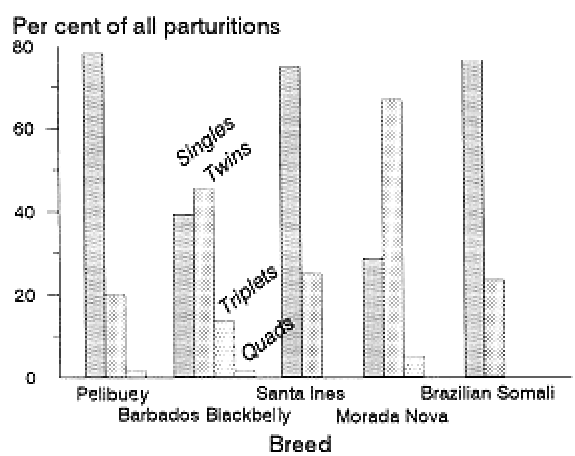


Fig. 9.6
Distribution of litter sizes in some tropical American sheep breeds.
(Source: adapted from Fitzhugh & Bradford, 1983.)

sponding figures for Pelibuey ewes were 81.9, 18.1, 0.5 and 0.0%.

The mean litter size of Mozambique Landim sheep was 1.48 ± 0.51 with differences being due to years and seasons of parturition (Rocha *et al*., 1990). Awassi ewes are notorious for small litter sizes. In an Israeli study (Gootwine & Goot, 1996) the number of lambs born per parturition for 677 ewes lambing over a 15-year period was 1.11 ± 0.02 compared with 1.60 ± 0.03 for East Friesian sheep kept under the same conditions and 1.271.48 for various levels of cross between the two breeds. The large litter size is the outstanding reproductive feature of Landim sheep. Landim sheep appear to have the largest litter sizes of all sheep in the Southern African region, as Tswana sheep have an average litter size of 1.02 (APRU, 1984), Sabi (= Zimbabwe) a litter of 1.10 (R. Sibanda, pers. comm.) and Dorper one of 1.09 (APRU, 1984) and several studies of the Blackhead Persian and its crosses attest to very small litter sizes. Comparable litter sizes to the Landim types have been recorded elsewhere in sub-Saharan Africa for the Rwanda subtype of the African long-fat-tailed sheep (Wilson & Murayi, 1988). In North Africa the D'man breed of Morocco is remarkably prolific with a range in ovulation rate of one to eight (Lahlou-Kassi &

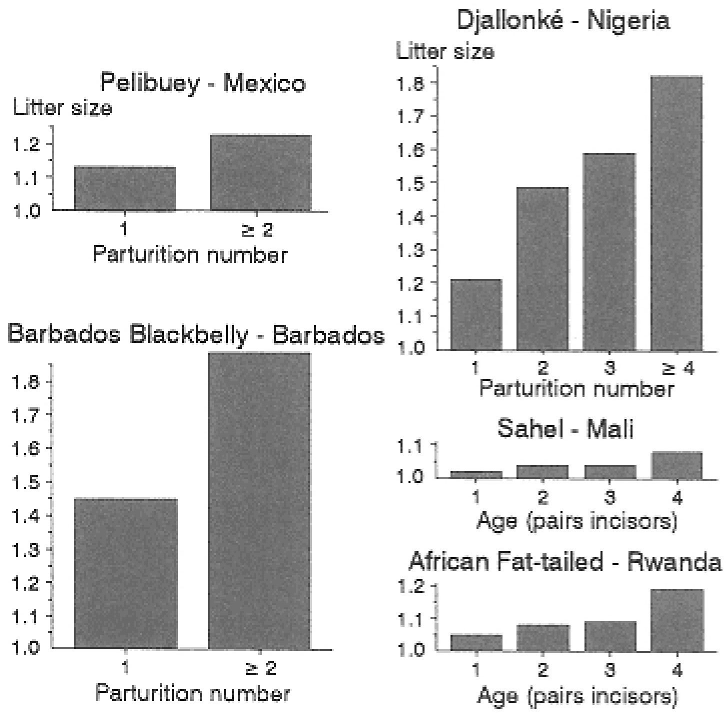


Fig. 9.7
Distribution of litter sizes in some tropical sheep breeds in relation to parity or age of dam.
(Source: Adapted from literature cited in reference list.)

Marie, 1985). Indonesian sheep are also very prolific and probably possess a gene with a large effect on ovulation rate (Bradford *et al*., 1986). In the wider context, the prolific character of many tropical sheep breeds (Mason, 1980) might well be used to improve reproductive performance of other indigenous sheep that have other adaptations to the harsh environments for which temperate sheep are not always suitable.

Annual Reproductive Rate

In view of the considerable variation in intervals between successive births and in litter size the number of lambs born per ewe per year is a good indicator of overall reproductive performance. This annual reproductive rate (ARR) (Fig. 9.8) is calculated as (litter size × interval between parturitions)/365. Landim sheep under station management in Mozambique had an annual reproductive rate of 1.38 lambs/ewe/year (Rocha *et al*., 1990).

Conclusions on Reproductive Performance of Tropical Sheep

In a general context analyses of data from many tropical research stations show the very large effect that management exerts on productivity. Ages at first parturition can be artificially delayed by imposing restrictions on time of first breeding related to an *a priori* mating season or a minimum weight. Long intervals between parturitions also result directly from management policies which impose a single short annual mating period on animals which are fertile all of the year round. Control of the breeding season to what is considered to be a 'best' period may have repercussions not only on annual and total lifetime reproductive performance but also on

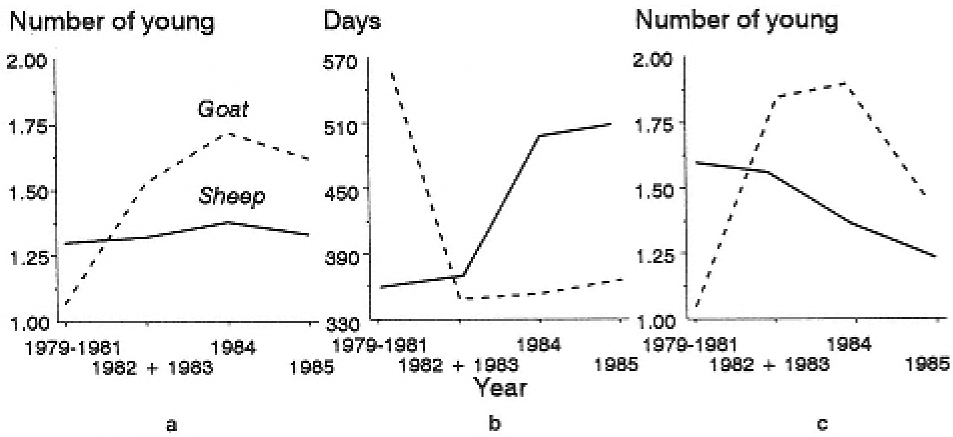


Fig. 9.8
Interannual variations in (a) litter size; (b) parturition interval and (c) annual reproductive rate in Landim sheep and goats.
(Source: Rocha *et al*., 1990.)

other aspects of production. Thus weights and growth of offspring may be adversely affected at critical periods (such as postweaning or at puberty) if consideration is given only to dam condition or reproductive status in the determination of management strategies. Mortality levels at various ages in relation to predisposing events earlier in an animal's career also need to be considered in any research programme designed to improve livestock performance. Correct interpretation of research results also requires that previous events (e.g. nutritional status at conception and not at parturition or lactation performance of the dam and not weight of young at a fixed period postweaning) be taken into account in order to understand fully the results produced. Preliminary analyses should be used to assist scientists in designing, as a necessary first step to genetic improvement, better management programmes (including nutrition and health interventions) in order that indigenous tropical livestock may best express their potential.

Nutrition

Almost all tropical sheep are maintained on unimproved grazing. In Africa and West Asia they are grazed extensively and often together with cattle and/or goats; in the more arid areas they are sometimes herded with camels. In parts of Asia, the Caribbean and the humid parts of Africa smallholder mixed farmers often tie their sheep along roadsides. On the island of Madura in Indonesia they are kept permanently indoors and fed cut forage and browse. In tropical Australia they are grazed very extensively, often in very large flocks but at stocking rates as low as 1.64.0 ha per sheep.

The sheep is a typical ruminant with a digestive system very similar to that of cattle but that is obviously commensurate with its size.

Feed Preferences

Sheep are intermediate bulk and roughage feeders (van Soest, 1982) with little ability to select a diet quality better than the average on offer. They do, however, prefer short grasses and low-growing herbs. A peculiarity of sheep is that, when transferred to a new area, they appear to have little instinctive knowledge of what forage is suitable and often do not thrive very well for quite a long period. In dry seasons and under conditions of low feed availability sheep are confronted with poor quality feed, low in protein and high in fibre and insoluble lignins. The species adapts to this situation by increases in fore-stomach volume and in fluid and small particle retention times in the digestive system that are relatively greater than for any of the other ruminating domestic animals. Volume increases of more than 50% allow fluid retention times to increase more than 75% and small particle retention times to increase by 45% when the diet is mostly dry and fibrous compared to when it is green. There are concomitant increases in digestibility of about 12%, which is also greater than for the other species.

Intake

It seems that feed intake varies among breeds independently of body weight. In South Africa, for example, daily dry matter intake of Merino, Blackhead Persian and Dorper breeds has been reported as 1.14, 0.93 and 1.27 kg/100 kg liveweight. If these data can be generalized it is possible that arid adapted sheep have lower requirements than other types which could account in large part for their survival in these areas.

Supplementary Feeding

As sheep tend to thrive best in drier climates where the feed supply fluctuates in quantity and quality from wet to dry season, supplementary feeding is often of importance during the dry season. Sheep can in fact be carried through drought periods on hay if it is available and, if this can be supplemented with about 100 g of a protein concentrate such as groundnut cake or cotton seed, normal growth and development may be maintained. Silage has been used in drought feeding programmes in Australia with a satisfactory ration being 1.01.5 kg silage of 56% crude protein content and 6090 g of a high protein meal. Well fed sheep produce a heavier but coarser fleece.

Where sheep are subject to a long dry season productivity can be greatly increased by supplementing their rations while they are on grazing and by managing those sheep destined for slaughter in a feedlot. Iranian sheep have been shown to respond to better feeding (Demiruren *et al*., 1971) and it is possible to produce ram and ewe carcases of 35 kg and 28 kg if they are managed under improved feeding conditions.

Good feeding is particularly important just before the breeding season begins if seasonal breeding is practised. Additional feed helps to improve prolificacy. It should be remembered, however, that under very poor feeding conditions multiple births are a liability. Good feeding is also needed during the second half of pregnancy.

Salt in one form or another should always be available for sheep. Individual needs are about 7 g/day. Other minerals and particularly trace elements such as copper and cobalt need to be available (or injected) if a deficiency is known or suspected.

If kept indoors the feed may comprise entirely succulent fodders or a mixture of forage and concentrates. On Madura, for example, even if sheep are tethered outside for part of the time they are always fed some freshly cut forage or browse indoors but concentrates are hardly ever used. Browse from the leguminous tree *Sesbania grandiflora* is a favourite feed. The Kikuyu tribe in Kenya feed sweet potato vines and groundnut haulm.

In general if suitable forage or browse is not available sheep may be fed up to 0.45 kg/day of a concentrate mixture. A suitable concentrate would comprise 90% of a mixture of cereals and cereal brans, such as maize and wheat, rice or sorghum bran or broken rice and rice bran, together with 10% of an oil cake such as groundnut, cotton seed or sesame meal together with a suitable mineral mixture. Feeding of small amounts of a good legume hay such as lucerne *Medicago sativa* or a little fresh green forage or browse would improve this type of concentrate and may be essential as insufficient carotene in a sheep's ration can cause vitamin A deficiency that results in infertility.

Sheep do not always drink water every day, especially if they are grazing lush wet season pastures but they should be allowed access to free water at all times if at all possible. Sheep managed under semi-arid tropical conditions have a requirement of about 45 litres of water per day. If dry fed indoors water should be available on an *ad libitum* basis.

Health

Resistance.

Resistance to disease is an approach to improving livestock productivity that has been under consideration for a long time but is now attracting strong interest. Animals bred for resistance to one or more diseases do not incur costs for prophylactic treatment or chemical curative measures and do not carry the risks of toxicity and contamination of their products. There is no associated risk that chemicals used for treatment will damage the environment nor is there the risk of parasites developing resistance to drug treatment. Resistance is a complicated factor and is expressed genetically via breed differences, within-breed differences and resistance to various diseases. There is, however, evidence that resistance to disease is favourably associated with production and especially with reproductive performance and mortality. Breeding for resistance is a slow process and should proceed only in parallel with other studies on the epidemiology and costs of disease, development of new vaccines, chemotherapeutic drugs, whole flock health management strategies and improvement of animal health delivery systems (Baker, 1995). The consequences of breeding for disease resistance also need to be assessed for diseases that are not subject to selection and productivity in terms of cash, investment, security and social and religious characteristics.

There is an increasing body of evidence of resistance to various diseases in sheep; a recent monograph on the subject edited by Gray *et al*. (1995) covers many tropical as well as temperate areas. In India, for example, there is evidence of differing susceptibilities by various breeds to sheep pox, blue tongue, ovine adenovirus, foot-and-mouth disease and roundworm infections. Reduced faecal egg counts (FEC) and the ability to maintain high packed cell volumes (PCV) are often used as indicators of disease resistance and particularly to internal parasites. There is also considerable evidence of similar variations in the Caribbean (Table 9.8), Southeast Asia and the Pacific Islands.

Tolerance is a trait that is difficult to distinguish in practice from resistance. There is, however, increasing evidence of tolerance to some diseases and to combinations of diseases by sheep. The most outstanding example is that of the Djallonké sheep of West Africa. Not as much work has been done on the mechanisms of tolerance in sheep and goats as in cattle but they are probably similar in their responses to disease challenge. Anaemia is a major symptom of trypanosomosis and this can be assessed relatively easily in terms of PCV in infected animals. The degree of parasitaemia is not so easily assessed by the most common methoddark ground/phase contrast buffy coat microscopic techniqueas is the PCV. Recent advances in antigen-detection enzyme immunoassays (antigen-ELISA), based on monoclonal antibodies that recognize trypanosome antigens specific to the particular disease, make this method of detection four times more sensitive than the buffy coat technique (Nantulya & Lindquist, 1989). Other new approaches include the latex agglutination antigen test (Nantulya, 1993). The results of this test can be read within 5 minutes very simply using heparinized whole blood, plasma or serum. These new tests combined with the traditional microscopic techniques are not only useful for detecting trypanosomosis but can also be used to provide indications of trypanotolerance in individuals or in populations of animals.

Major Diseases and Parasites

Diseases and parasites exact a heavy toll on sheep and mortality can be high in both the humid and dry tropics. In Africa, in particular, up to 30% of lambs die before they reach 6 months of age (Wilson, 1976; Wilson & Light, 1986; Wilson & Murayi, 1988). Neonatal mortalitythat is within a few days of birthis particularly high in some areas and at some seasons. Adult mortality is regularly 10% or more per year in many traditional flocks. In the humid tropics respiratory diseases and internal parasites are probably the major causes of mortality. In the drier areas the poor milking ability of ewes coupled with competition with the lamb by humans for milk con-

Table 9.8 Evidence of breed resistance in natural infection of Caribbean and native American sheep breeds. (*Source*: Zajac, 1995.)

Breed	Compared with	Age	Result
Barbados Blackbelly; Blackbelly × Dorset	Dorset and domestic crosses	Ewes and lambs	Reduced faecal egg count
Florida Native	Rambouillet, Hampshire	Ewes and lambs	Reduced faecal egg count and *Haemonchus* numbers; reduced haemoglobin
Florida Native	Rambouillet	Ewes	Reduced faecal egg count, reduced packed cell volume, haemoglobin
Florida Native, St Croix, Barbados Blackbelly	Rambouillet, Finn-Dorset × Rambouillet	Ewes	Reduced or absent Peste des Petits Ruminants
Florida Native, St Croix	Finn-Dorset × Rambouillet, Barbados Blackbelly	Ewes	Reduced faecal egg count and no difference in worm burden
Florida Native	Dorset × Rambouillet	Ewes	Reduced faecal egg count and worm burden throughout pregnancy
Navajo	Suffolk, Targhee, Rambouillet, Corriedale	4 months	Reduced *Haemonchus* numbers
St Croix	Dorset	2 months	Reduced faecal egg count and *Haemonchus* numbers; reduced globule leucocytes

tributes to high death rates or general morbidity, slow growth rates and consequent lack of resistance to diseases. This is sometimes known as the SME (starvation, mismothering, exposure) syndrome (Chaarani *et al*., 1991). In the United Kingdom 41% of deaths in lambs are directly due to mismothering and subsequent starvation and 11% of disease related deaths are due to inadequate colostrum intake. It is a truism that it cannot be overstated that diseases and parasites in sheep, and particularly in lambs, can best be overcome by good management, proper feeding and strict attention to general animal health.

Infectious Diseases

It is likely that all the common sheep diseases including anthrax, black quarter, navel ill, pulpy kidney disease and leptospirosis are present throughout the tropics as well as some that are of special importance (Table 9.9). Sheep are, however, free of some of these diseases on some tropical islands. Peste des petits ruminants, a virus disease related to the rinderpest of cattle and which can be partially controlled by vaccination with cattle rinderpest tissue culture vaccine, affects goats more than sheep but seems to be assuming more importance in the species over wide areas (Hill, 1983).

Internal Parasites

Sheep are probably more susceptible to the ill-effects of internal parasites than any other quadruped livestock species. As already indicated for the Masai sheep, however, some breeds appear to be tolerant of or resistant to some internal parasites. The indigenous Florida sheep, for example, is somewhat resistant to *Haemonchus contortus* and this may be related to the presence of haemoglobin type B in the blood (Jilek & Bradley, 1969). Barbados Blackbelly sheep are

Table 9.9 Major sheep diseases in the tropics and subtropics.

Disease and prevalence	Causal agent and form of transmission	Main symptoms	Treatment and/or control measures
Blue tongue; Africa, Asia, Americas (mainly in 'exotic' stock)	Virus (at least 16 antigenic strains); transmitted by sandflies, sheep ked and mosquitoes	Fever, inflammation and ulceration of mucous membranes, purple and swollen tongue; mortality can be high	Annual vaccination in infected areas; stringent control on entry elsewhere
Footrot; worldwide	Bacterium (*Fusiformis nodosus*) usually in association with spirochaete (*Spirochaete penortha*); carrier or infected ground	Severe lameness; hoof tissue breaks away from underlying infected tissue	Cleaning and cutting away of infected tissue with use of antibiotics or astringent such as 5% copper sulphate solution or 5% formalin; footbaths of these solutions and general foot hygiene and regular trimming; vaccine developed in Nepal
Haemorrhagic septicaemia or pasteurellosis; worldwide	Bacterium, usually *Pasteurella multocida* type 1, that live permanently in the animal; transmitted by carrier animals from season to season	Occurs during stress periods particularly at onset of rains after dry season when bacteria become pathogenic; high fever, heavy respiration and salivation, dark red membranes	Sulphur drugs; vaccines from local strains effective to varying degrees if administered some weeks before usual infective period
Heartwater; Africa	Rickettsia (*Cowdria ruminantium*) transmitted by *Amblyomma hebracum* tick	Fever, laboured breathing, loss of appetite, muscular tremors and convulsions ('nervous symptoms'); death	Antibiotics; control of tick with acaricides; inoculation of young with infected blood as soon after birth as possible
Infectious kerato-conjunctivitis or pinkeye; pantropical	Rickettsia (*Cowdria conjunctivitis*) in presence of bacterium (*Neisseria ovis*); spread by droplets, dust and flies especially in dry weather	Lachrymation ('tears') followed by clouding of cornea	Ophthalmic therapeutic agents such as 5% zinc sulphate solution; partially effective vaccine
Rift Valley Fever (RVF), also known as enzootic hepatitis; East, South and West Africa	Virus; insects, mainly mosquitoes, are vectors between animals	Fever in lambs accompanied by high mortality; some abortion in pregnant ewes	No treatment; vaccinate lambs; [disease is a zoonose and also affects man]
Sheep pox; North, West and South Africa and	Parapox virus; direct contact is usual mode of transmission	Depression, fever, eye and nose discharges and pox lesions in lambs in which mortality can be	Aluminium gel absorbate vaccine provides 1-year immunity; vaccines from local strains; some immunity conferred by prior

Ethiopia	high; pox lesions around mouth and under tail in adults but low mortality	infection

also considered to be particularly tolerant of internal parasites.

Nematodes or Roundworms

Major internal parasites of sheep are large stomach worms (*Haemonchus* spp.), brown stomach worms (*Ostertagia circumcinta*), black scour worms (*Trichostrongylus* spp.), nodular worms (*Oesophagostomum* spp.), intestinal thread-worms or *Strongyloides*, whipworm (*Trichuris ovis*), hookworms (*Bunostomum trigonocephalum*), and the lungworm (*Dictyocaulus filaria*). All of these have a somewhat similar life cycle and, except for the lungworm, adults live in the animal gut. Here they mate and the female worm then lays enormous numbers of eggs that are voided with the faeces onto pastures. Under suitable conditions of moisture and temperature the eggs hatch in 12 days and develop into larvae, some of which are then ingested with grass by grazing stock. The adult lungworm differs from this pattern in that the adults live in the bronchi and lay eggs which are coughed up or are swallowed and pass out with the faeces.

Internal parasite control is effective, even if anthelmintics are used, only if sheep are well managed and an integrated approach is adopted. Strict rotational grazing and the concept of 'clean' pastures is one aspect of this approach. Well-fed sheep do not suffer in the same way as those that are undernourished. In the dry tropics good management can mean that no control measures are needed but in the humid tropics some chemical treatment may be necessary. Anthelmintics with short residual periods and not harmful to the environment should be used if possible. New administration techniques such as 'pour on' and slow release boluses can not only reduce the cost of treatment but also render it more effective. Some new drugs also control lungworm but vaccination of young animals can reduce problems in later life by limiting the effects of re-infection.

Cestodes or Tapeworms

The sheep tapeworm *Coenurus cerebralis* is of importance only where there are numerous dogs in contact with the flock as the dog is the alternative host of this parasite. Dogs that eat infected sheep meat void eggs on pastures and in holding grounds which are then ingested by sheep. When the eggs hatch the larvae first enter the blood stream and then the central nervous system where they create large cysts. The pressure of these on the nervous system causes partial blindness and sheep show nervous symptoms characterized by unsteady gait which in Britain is known as 'gid' or 'staggers'. There is no effective treatment of this disease so prevention is certainly the best cure.

A tapeworm of dogs and wild carnivores *Echinococcus granulosus* is of some importance in sheep and is also a zoonose that infects man as both are alternate hosts of the larval stages of the parasite which are known as hydatid cysts because they are usually filled with a watery fluid. The effects of the cysts depend to some extent on the location in the host's body, usually the lungs or liver, but they can be severe or even fatal. Another common tapeworm is *Taenia saginata* which often completely blocks the small intestine, especially of lambs, and causes rapid death. *Stilesia hepatica* is a liver tapeworm whose main economic effects are condemnation of livers at abattoirs. Both of these last two can be treated but this is expensive and not necessarily 100% effective.

Trematodes or Flukes

Sheep are very susceptible to infection by the liver flukes *Fasciola hepatica* and *F. gigantica*. The latter is more common than the former as *F. hepatica* may be restricted to highland areas in the tropics. Infected sheep void eggs that quickly hatch and are then ingested by the alternate host which is a snail, usually of the genus *Bulinus*. The larvae go through several development stages before leaving the snail and encysting on the pasture. When eaten by sheep the cysts develop into larvae that penetrate the intestinal wall and migrate to the liver where they mature in 23 months. Control is possible by multiple drenching with one or more of several proprietary drugs but is expensive and has to be repeated at regular intervals if management is not of a high standard. Once again an integrated approach involves pasture management, and especially the avoidance of grazing of wet herbage or in wet areas, together with the treatment of pasture or water with copper sulphate that is designed to kill the snails or reduce their incidence.

External Parasites

External parasites of sheep encompass flies (including the wingless sheep ked *Malophagus ovinus* and blowflies whose larvae are known as maggots), mites, lice and ticks. These are often considered to be less harmful than internal parasites but they still cause immense economic loss.

Flies

The harmful effects of the many types of fly that pester sheep range from the mechanical (causing animals to fret, not feed and thus lose weight) to acting as disease vectors.

Tsetse flies of the genus *Glossina*, for example, carry trypanosomosis in many parts of Africa whereas midges or mosquitoes of the genus *Culicoides* are vectors of blue tongue. The sheep nasal fly. *Oestrus ovis*, lays its eggs in the nostrils of sheep where the larvae hatch and cause great distress to the animal often manifested in nervous symptoms. Readily available, safe and long-lasting insecticides, including the pour-on version of ivermectin, are effective against the pest. The larvae of the many types of blowflies cause considerable damage to the skin and wool or hair of sheep by their burrowing habits and through eating of the living flesh; the condition is often known as 'myiasis' but this term also has more general application for all types of damage due to flies. These can also be treated or prevented by modern broad-spectrum anthelmintics. A recent example of a disaster avoided is the successful campaign against the New World Screwworm, *Cochlyomyia hominivorax*, which was inadvertently introduced from Mexico to Libya and controlled by an integrated campaign including initial inspection of animals, a ban on livestock movements, chemical treatment, use of sterile males, slaughter of badly infected animals and education of livestock owners as to the potential economic and other losses including infection of themselves (Lindquist & Abusowa, 1991).

Mites.

Several species of mite, of which the commonest in the tropics is *Sarcoptes scabiei* var. *ovis*, attack sheep and cause the condition known as mange. Mites occur throughout the tropics, pass all stages of their life cycle on the sheep host and are transmitted by contact between animals or from infected structures such as sheds or holding pens. They can be controlled by dipping or by the newer broad spectrum anthelmintics.

Lice

Lice, like mites, demonstrate marked host specificity. They are not important as disease vectors but can cause tremendous damage to their host in general debility through the effects of their blood sucking and through direct damage to the skin which then has greatly reduced value.

Ticks

The many types of tick affect sheep directly and act as vectors of disease. In particular, in West Africa, they act as vectors of heart water caused by the rickettsia *Cowdrium ruminantum*. Djallonké sheep appear to be resistant to this disease but the Sahel sheep that are their northern neighbours are susceptible to it; 'improving' the Djallonké with the Sahel may therefore render it susceptible to this disease.

Other Causes of Ill Health

Metabolic disturbances such as toxaemia are also important causes of economic loss. Enterotoxaemia is an acute disease of ruminants and especially of sheep caused by the proliferation of various serotypes of *Clostridium perfringens* in the intestine where they produce toxins which diffuse in the blood and often prove fatal to the

animal. A sudden increase in the *Clostridium* population is associated with nutritional factors. It usually happens in well-fed animals with a diet rich in nitrogen but poor in fibre, and when intestinal transit is slowed. A very rapid modification of the ration can cause this imbalance in the intestinal population of microorganisms, a situation often observed at the beginning of the rainy season in arid or semi-arid zones when animals change from a dry and limited diet to a green and abundant one. The increase in internal parasite burdens at the start of the rainy season is often linked to the imbalance.

There is a low prevalence of fungal diseases such as ringworm in tropical sheep. Diseases due to mineral deficiencies or imbalances are, however, of considerable importance (McDowell, 1985) especially as it is rare for extensively managed sheep to be given a supplement and many tropical areas are known to be lacking in or have an excess of some macrominerals and microelements.

Photosensitization may be relatively common in some areas of the tropics. The eating of some plants, especially *Lantana camara*, is often the root cause of the problem. Changing the diet and keeping sheep in a dark shed or shaded area helps to overcome the ill-effects.

Management

Castration and tail docking are two of the main management practices influencing sheep productivity. Castration can be done by the open method using a knife (or better an emasculator which abrades the cords and blood vessels) or by closed methods such as an elastrator or burdizzo. Castration does not affect the rate of gain of some breeds to 6 months of age as, for example, in Iran (Demiruren *et al*., 1971). It should be noted, however, that castration is not a common or accepted practice in many Muslim areas.

Docking of the tail is desirable in woolled breeds as it reduces the influence of blowfly strike. Sufficient tail should be left to cover the anus and the female genital opening. It has been shown (Qureshi, 1968) that the docking of fat-tailed sheep increases the dressing percentage and improves fat deposition, finish and quality. There is also evidence that lamb birth weights are higher in docked than in undocked sheep (Qureshi & Shaw, 1968). Docking of Iranian sheep increased the lean and decreased the fat content of the carcases (Demiruren *et al*., 1971). The evidence on docking is, however, conflicting. In South Africa slightly heavier live and carcase weights were found in undocked compared to docked fat-tailed lambs with the differences being accounted for almost entirely by more caudal fat. There was no evidence to suggest that there was an increase in the deposition of internal or subcutaneous fat following docking. Docking may be advantageous in fat-tailed sheep if they are to be mated to rams of breeds that are not fat-tailed. This is because thin-tailed breeds lack the behavioural mechanism of flicking the fat-tail of the ewe aside when copulating. Unless thin-tailed rams are helped to mate fat-tailed ewes in the absence of docking, the reproductive rate may be less than satisfactory.

Weaning is usually done at 45 months. In Iran it has been shown that the rate of gain of lambs is significantly affected by the length of the suckling period up to 120 days from birth and that lambs should not be weaned too early (Demiruren *et al*., 1971).

Woolled sheep should be shorn once a year for best quality wool although shearing twice a year is practised by some tribes who have need of a more constant cash flow and where staple length is not a consideration (Wilson, 1983). Shearing should be done at a time of year when stress is at a minimum. One skilled man can shear up to 120 sheep per day.

Dentition and Age

The dental formula of sheep is the same as that of cattle, buffaloes and goats. There are, as in all animals, two sets of teeth; the temporary, deciduous or 'milk' teeth which are gradually replaced by the permanent teeth at more or less fixed intervals (particular to each species) as the animal ages. There are four kinds of teeth within each set, these being incisors (I), canines (C), premolars (P) and molars (M). Ruminants do

not have incisors in the upper jaw where they are replaced by a hard pad against which the lower teeth grind the food as it is taken into the mouth. Ruminants also lack the canines as such, these being replaced by a pair of incisors. The four pairs of incisors in ruminants are known as corners (the outside ones), laterals (the next-to-outside ones), medials (next-to-inside ones) and centrals. The dental formulae are:

Deciduous teeth:

$$\left(I\frac{0}{3}\quad C\frac{0}{1}\quad P\frac{3}{3}\right)\ 2 = 20$$

Permanent teeth:

$$\left(I\frac{0}{3}\quad C\frac{0}{1}\quad P\frac{3}{3}\quad M\frac{3}{3}\right)\ 2 = 32$$

It is often assumed that the teeth of early maturing breeds erupt at an earlier age than those of late maturing ones but there is no evidence in support of this. Within the same breed, however, the teeth of faster growing individuals do erupt earlier than those of slower growing ones.

Teeth development can be used as a proxy for age for animals for which the birth date is not accurately known. It has usually been considered, based on the Blackhead Persian breed in South Africa (Starke & Pretorius, 1955), that tropical sheep with two permanent incisors (one pair) are aged 1420 months, those with two pairs (four tooth) 2125 months, those with three pairs 2632 months and those with four pairs older than 32 months. In semi-arid West Africa ages at eruption of these four pairs of incisors in Sahel sheep have been shown to be 15.3 months, 22.0 months, 27.9 months and 38.2 months (Table 9.10). It has also been usual to consider that the age of eruption in goats is the same as for sheep but the evidence from West Africa (Wilson & Durkin, 1984) is that the first pair of permanent incisors of goats erupt about 1.2 months earlier than those of sheep (at 14.1 months), the second pair 2.5 months earlier (19.5 months), the third pair 3.8 months earlier (24.1 months) and the fourth pair 6.7 months earlier (31.5 months).

Table 9.10 Age at eruption (days) of permanent incisors in goats and sheep in Mali. (*Source*: adapted from Wilson & Durkin, 1984.)

Species	Number of pairs of permanent incisors			
	One	Two	Three	Four
Goat	429	595	734	959
Sheep	465	669	850	1164

Production and Productivity

The major contributions of sheep to human welfare are meat, wool, milk and skins (Table 9.11). In this context it is Asia (including China) that produces the most meat, milk and skins and Oceania that produces the most wool.

Growth and Weight for Age

Most tropical sheep are best known for their ability to survive harsh environmental conditions, low nutritional standards, high disease challenge and poor general management standards and there has, therefore, been little selection for rapid growth.

Growth and weights at given ages are, however, important factors in the determination of profitability and the success of an enterpriseeven in traditional systemsin which the aim is to produce meat. In the female, rapid growth leads to early puberty which in turn allows the production of more young during her life and may thus contribute to a reduction in the generation interval. Rapid growth in the male allows sales for meat to be made at an early age which in its turn increases income and may well allow a reduction in the stocking rate. Heritability and repeatability estimates and phenotypic correlations can be successfully used to improve the performance of most tropical sheep. Under good management and with a clearly defined selection principle, tropical indigenous breeds can be improved rapidly in terms of weight at age and growth rates and this can most probably be achieved without their losing the most import-

Table 9.11 World production of sheep meat, greasy wool, milk and skins (000 t) in 1994. (*Source*: FAO, 1995a.)

Region	Total sheep (million)	Meat	Wool	Milk	Fresh skins
Africa	208.8	890	229.3	1542	160.1
Asia	340.1	2342	538.9	3682	927.4
Europe	130.7	1242	248.3	2608	220.1
North America	17.5	199	37.3		23.7
South America	94.0	292	241.9	34	72.3
Oceania	182.8	1124	1013.0		230.3
World	1086.7	6886	2665.7	7981	1647.2

ant adaptability factors they often have to stressful local environments (Wilson & Light, 1986).

Weight at birth is an important factor in survival and for future growth rates. It is influenced by many factors including breed, season and year of birth, parity, type of birth and sex (Villette-Houssin & Theriez, 1982). There are usually differences in weights of lambs born of different ewes regardless of age but young out of primiparous ewes are almost invariably lighter than lambs out of multiparous ewes. Lambs sired by different rams normally also show significantly different weights at birth. The heritability of this trait calculated by the half-sibling method is usually about 0.280.32. Selection for birth weight should therefore provide good opportunities to improve weight performance.

Liveweight gain of Djallonké sheep from birth to 3 months is generally about 4050 g/day (Rombaut & van Vlaenderen, 1976) but can be twice this rate if good feed is provided (Berger, 1983). In larger sheep from semi-arid African environments the normal range of daily gain of traditionally managed sheep is 70120 g (Wilson, 1982) but under good feeding and management conditions the 120 g of Sudan Desert sheep can be increased by 50% to 180 g (El Amin & Sulieman, 1979), but even this can be 'forced', to 251 g, under feedlot conditions (Osman *et al*., 1968). In semi-arid Venezuela the average daily gain of West African 68 month old wethers was 77 g on a pasture of Guinea grass *Panicum maxicum* alone but when kept in semi-confinement with a concentrate supplement to the Guinea grass pasture, daily gain was 172 g: dressing percentage in this second group was 43.2 compared to the 40.8 of the pastured group (Stagnaro, 1983). Thus it can be seen that if economic conditions are favourable some breeds of tropical sheep provided with proper feeding, disease control and management can be quite productive on a lifetime basis especially as they can breed all year round.

Early investigations suggested that crossbred progeny of exotic and tropical sheep might grow more rapidly to weaning but then failed to maintain the advantage as adults under local environmental conditions. In Israel Awassi × Dorset Horn animals grew 2030% faster than purebred Awassi during the first 90 days of life. In India liveweight and wool yield of Romney Marsh × Nilgiri crosses were higher than indigenous Nilgiri over a 4-year period (Ramamurti, 1964). In Uganda Dorset Horn × East African Blackhead were heavier at birth than the pure native breed and grew at 90 g/day from weaning to maturity compared to 36 g/day but had a higher mortality rate of 26.1% compared to 21.0% (Trail & Sacker, 1966). Quarter-and half-bred Dorset ewes were also better milkers than the native breed and five-eighths and three-quarter-bred lambs were heavier at 2 months and at maturity than the pure Blackhead (Trail & Sacker, 1969). These data show some possible avenues for development but until better conditions of feeding, health and management can be assured on tropical ranges and in village small-scale production systems the uptake of crossbred stock will remain limited.

Repeatability of weights from 8 to 18 months is rather high under normal circumstances. Selection of future breeding females should therefore be relatively easy following first parturition. Phenotypic correlations between weights at different ages are also high ($r > 0.50$) and usually highly significant. Males could therefore be selected first at 3 months with a second selection at 18 months.

As adults, sex is usually the only factor within breeds that has a significant long-term effect on weight. In Rwanda, for example, adult females weighed 35 kg at 5 years while males at this age weighed approximately 45 kg (Murayi & Wilson, 1990). Postpartum weights usually increase from first to senior parities. Weight at 150 days postpartum may not show the same pattern of development and it may not be until the third parturition that females lose weight during the lactation period. This appears to indicate that young mothers use less energy in feeding their lambs than do older females but instead use considerable amounts of energy for their own bodily growth. This resource partitioning is reflected in a slower growth rate of young out of lower parity dams.

Meat

World production of sheep meat increased by about 22% from 1980 to 1994 (FAO, 1995a). Production in centrally planned and developed countries remained static or rose only slightly but in developing countries there was considerable expansion. The major proportional increase was in Asia (67%), followed by Africa (22%) and then by South America (12%). In 1994 the developing countries in Asia, Africa and South America produced about 51% of all the world's sheep meat (Table 9.11). Asia produces about 34% of world sheep meat, Africa about 13% and South America about 4%. In Africa meat from sheep is estimated at 57% of total small ruminant meat production and small ruminants together contribute about 18% of all meat eaten. As almost all small ruminant meat is from indigenous production and much of the beef is imported it has been estimated (Wilson, 1984) that small ruminants contribute about 30% to indigenous meat production in Africa while being equivalent to about 17% of the standing domestic herbivore biomass.

The lean meat of the carcase represents the main protein source from a slaughtered animal and depends mainly on species, age, liveweight, sex and plane of nutrition. In general, goat carcases appear leaner than sheep carcases and have a lower fat cover. Sheep have more fat and less protein in their meat than goats. With increasing age, liveweight and plane of nutrition, the proportion of lean meat in the carcase decreases. The proportions of lean meat also depend on the part of the carcase being examined. The leg and loin generally have the highest meat content while shanks and breast have the lowest meat but the highest fat proportion. The blood of the animal accounts for 3.5% of the liveweight. It is a source of high quality protein but is not widely used except by some Kenyan and Tanzanian tribes.

The dressing percentage of many tropical sheep breeds is rather low. In Hejazi sheep it is 3740% (Epstein, 1954) and in Sudan Desert sheep may also be as low as 36% but can be much higher in fattened sheep (Osman & El Shafie, 1967). Other breeds have higher dressing percentages as, for example, the 48.659.1% of Awassi sheep aged 310 months (Epstein, 1977). Average dressing percentages of tropical sheep are therefore probably in the range 4050% but dressing percentage is a measure of productivity rather than of quality. The latter factor is hard to define but many eaters of sheep meat agree that the product of at least some tropical breeds is 'sweet' and of high quality.

In unfattened and fattened Sudan Desert sheep and goats dressing percentages increase with age. This increase is due to faster growth rates of muscle and fat and slower growth rates of early developing parts. Muscle and fat are late developing tissues relative to bone and therefore older animals have a lower proportion of bones in their carcase than younger ones. The reduction of bone proportion with increasing age is more pronounced in fattened than in unfattened animals (Gaili *et al*., 1972).

Dressing percentages usually increase with increasing proportions of concentrates in the ration. High percentages of crude fibre and roughages with low digestibility contribute to low dressing percentages. This is mainly due to a reduced proportion of digestive tract contents in animals fed concentrates. Animals fed on a high concentrate ration have a higher proportion of fat while muscle and bone proportions are lower than in animals fed restricted levels. Feeding is the most important factor influencing meat production and carcase quality. Because of the high real and opportunity costs of concentrate diets, future nutritional research activities must be aimed at defining the value of crop residues and agro-industrial by-products and developing feeding strategies which will state levels and durations of supplementation to optimize meat production and its efficiency.

Skins and Fibres.

Skins

Small ruminant skins are an important by-product of animal production in the tropics. In many countries they contribute considerably to the national treasury and could do so in many more. In almost every country they have suffered from neglect in extension and marketing services in spite of their importance to national and household economies, and their full potential is almost nowhere being realized. Niger, and to a lesser extent Nigeria, are the only countries where research and development programmes have been pursued and the results of this work are evident in the high regard in which their skins, especially those of goats, are held in the world market. Most skins are used internally in tropical countries' economies but in some countries contribute considerably to export revenue. In Botswana, in 1985, revenue to the Botswana Meat Commission from sheepskins was about 25% of mutton value and the value of goatskins was equivalent to 20% of that obtained from goat meat (Botswana Meat Commission, 1986). In Ethiopia in 1983 a total of 3.3 million sheepskins and 1.8 million goatskins earned export revenue equivalent to 9.2% of all agricultural exports but to 29.5% of exports excluding coffee (Central Statistical Office, 1984).

The skins of Sudan Desert sheep range between 8.8 and 11.0% of liveweight while goats of similar age classes have lighter skins representing between 7.2 and 8.9% of liveweight (Gaili *et al*., 1972). Sahel goats have lighter skins as a proportion of liveweight (6.7%) than Sahel sheep (7.1%) (Wilson, 1984).

Wool

The 59% of the world's sheep in Asia, Africa and South America produce only 38% of the world's wool and most of this is in the lower quality classes. Less than 50 000 t of greasy wool and less than 25 000 t of scoured are produced in sub-Saharan Africa (Table 9.12) and almost all of this is used locally. Sudan (16 000 t), Ethiopia (12 500 t) and Zimbabwe (10 000 t) are responsible for almost the whole of African production of

Table 9.12 Skins and wool production in the world and total and percentage production of major tropical regions in 1994. (*Source*: adapted from FAO, 1995a.)

Product	World production (000 t)	Africa		Asia		South America	
		000 t	%	000 t	%	000 t	%
Fresh goatskins	623.0	114.6	18.39	460.2	73.87	13.7	2.20
Fresh sheepskins	1647.2	160.1	9.72	927.4	56.30	72.3	4.38
Greasy wool	2665.8	229.3	8.60	538.9	20.22	174.3	6.54
Scoured wool	1713.5	118.7	6.93	281.9	16.45	141.6	8.26

greasy wool while Lesotho (3000 t) and Kenya (2000 t) reputedly produce surprisingly small amounts. Wool from other tropical areas is relatively unimportant in world production and trade, although the subtropical areas of Australia do, of course, contribute much to the world market. In general wool imports greatly exceed production as a whole in the tropics.

As tropical countries industrialize, wool production becomes more important because demand increases as textile industries develop. Efforts are being made by many countries to produce more better quality wool, notably in India and West Asia, where considerable success has been achieved in crossing Merino and other fine wool breeds on coarse and carpet wool types. This seems to have had only minor repercussions on the oriental carpet trade which indeed is one of the few tropical products that has maintained its value and even exceeded the generally high levels of inflation prevailing in those areas.

Wool yields of tropical sheep are not only of poor quality but generally of low quantity. Unimproved Awassi yield 1.41.6 kg (Asker & Juma, 1966) but 35 years of breeding for milk production in Israel also raised wool yields by 50% (Epstein, 1977). In Iran the 12-month fleece weights of the Kelakui breed were 1.63 kg for females and 2.27 kg for males, for Kizil were 2.15 kg and 3.21 kg, for Bakhtiari were 2.29 kg and 3.36 kg and for Baluchi were 2.49 kg and 3.31 kg, respectively (Demiruren *el al*., 1971). In Africa the combined yield of Macina sheep clipped twice per year is less than 900 g (Wilson, 1983).

Karakul Pelts

Karakul pelts from the tropics that are sold on the world market, except for a minuscule number produced in Botswana, are almost exclusively the domain of Namibia, with production varying from 1.3 million to 4.9 million units per annum in the 10-year period 197483. A small number of Karakul sheep, first imported from neighbouring South Africa during the 1950s, were kept on about 200 farms in the extreme

Fig. 9.9
Karakul lambs about 1-month-old in southwest Botswana howing different pelt types.

southwest of Botswana during the 1980s. Karakul productivity is expressed by the number of Karakul pelts per ewe per unit time. In Botswana this was affected by low reproductive and high mortality rates leading to a high requirement of animals for flock replacement and a consequent decrease in the number of pelts. A high mortality of 22% was caused by malnutrition, jackals, diseases and ageing (Christine Martins, pers. comm., 1987).

Lambs used for pelt production (Fig. 9.9) are slaughtered the first day after birth, otherwise the characteristic curls and patterns disappear. Slaughtering and skinning is done by knife and by hand. Tissue and fat are removed with a knife and blood and dirt washed out with cold water. The wet pelt is spread on a frame covered with jute and dried in this form in the air. Most pelts are shipped to London for classification according to a standard system (Fig. 9.10). The prices of pelts are related to:

• *Colour*. Grey pelts are better priced than black ones. Prices for checkered pelts are very low owing to low demand and inferior quality.

• *Pelt size*. Pelt size depends on litter size and the nutrition and age of the ewe. Pelts smaller than a standard fetch much lower prices.

• *Curl type*. The breeder distinguishes among the shallow types in Galliac (almost without curls), Watersilk, Shallow and Shallow Developed, and among the curl types in Developed Shallow and Pipe Curl but there are many in-

<- == (decrease) == Hair length and spacing (curl size) == (increase) == + >

Curl development (<- == == + >)	Short (small curl)	Medium (medium curl)	Long (large curl)	Overgrown
Galliac Watersilk Shallow	S D P light	D D flat		RF
Shallow Developed and Developed Shallow	F — M	KF	NF	RB
Ribbed	C	T	V	:
DS/PC and Pipe Curl	G	KG	NC	RC

Fig. 9.10
A schematic classification of Karakul pelts as used at London auctions: letters in body of figure are grades assigned on basis of hair and curl characteristics.
(Source: Christine Martins, pers. comm., 1987.)

termediate types. The shallow types were bred from the curl types in the 1920s. Only four classes are recognized on the market, these being Shallow, Developed, Ribbed and Curl. Better prices are achieved for shallower types.

• *Hair length and curl size*. Hair length and curl size affect price. 'Good' is short hair or small curls and 'bad' is overgrown hair and curls. Overgrowing is more common in years of good nutrition.

• *Hair quality and pattern*. Hair quality is determined by lustre and texture while pattern has a considerable influence on the attractiveness of a pelt. Hair quality and pattern therefore have high economic value.

Hair

Hair from sheep is not much used except for local manufacture but it may be quite important in this context. The Black Maure sheep is part of the West African Sahel group and has been developed particularly for hair production. Its natural range is northern Mali, northern Senegal and Mauritaniawherever, in fact, the Moor tribe is found. The hair is used mainly for blankets and for the manufacture of the tents (Fig.

Fig. 9.11
Maure sheep and a tent made from their hair on a millet stubble field in northern Mali.

9.11) which are the homes of the nomadic owners. In the traditional system hair is usually cut by a double-bladed knife several times a year, total annual yield being about 200 g per head. Mean fibre length is 33 mm and fibre diameter about 26.6 µm (Wilson, 1983).

Milk

Small ruminants produce lower absolute quantities of milk than do cattle. Taking into account body weight or metabolic weight, however, their milk yield is higher than other species with the possible exception of the camel. These minor supplies are, when all else fails, available during the most difficult periods of the year in many countries (Fig. 9.12). In India and Western Asia

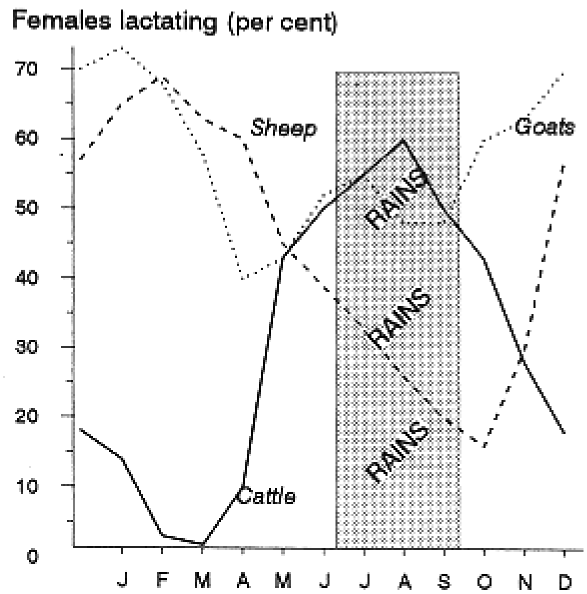


Fig. 9.12
The percentage of lactating females of three different species at different times of the year in Sudan.
(Source: Wilson, 1991.)

much of the animal protein consumedand an important part of the total dietis in the form of sheep milk. Small ruminants are thus an important potential source of milk for human nutrition. Milk from sheep is a relatively more important source of food for humans in the tropics than is milk from goats. Most tropical countries are net importers of milk, in whatever form, and of butter and cheese (FAO, 1995a, 1995b). In 1989 estimates of the net cost of these imports amounted to about US$40 000 million (Fig. 9.13). Regional variations in production and consumption are not a simple function of animal numbers or of species composition. Production of milk, and of milk products, from and for the traditional sector, is largely a reflection of cultural background. Consumption habits, on the other hand, have been greatly modified in recent years by commercial imports and by aid-related or subsidized transfers. In spite of the small amount of milk used by humans from sheep and goats these species contribute more, in relative terms, to the total milk available for human consumption in the tropics than they do in the world as a whole (Table 9.13).

Almost all milk from tropical sheep and goats with the exception of some peripheral areas is, however, consumed by their offspring. Milk represents virtually the only source of feed for lambs

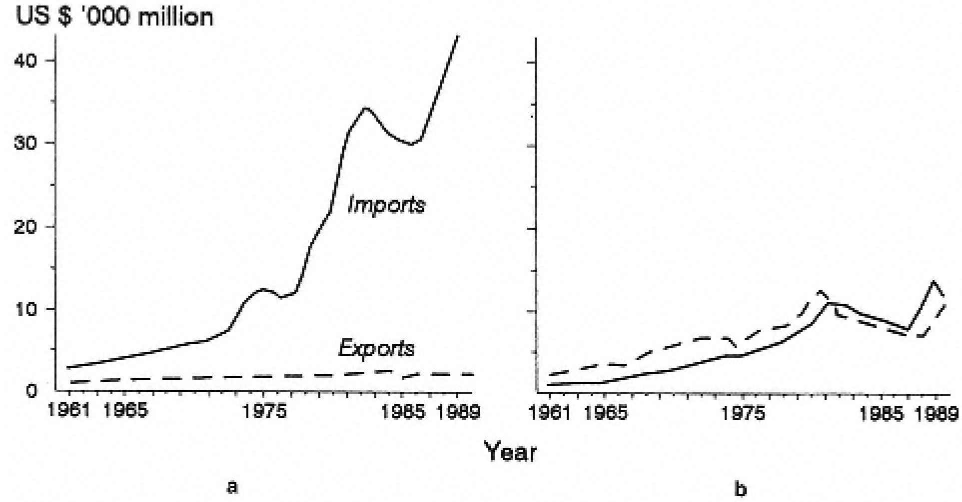


Fig. 9.13
Value of (a) dairy and (b) meat imports and exports in developing countries, 19611989.
(Source: Sancoucy *et al*., 1995.)

Table 9.13 Milk production from three principal species of domestic ruminants in the world and in the main tropical regions in 1994. (*Source*: adapted from FAO, 1995a.)

Product	World production 000 t	%	Africa 000 t	%	Asia 000 t	%	South America 000 t	%
Cattle	458 645	100.00	15 197	3.31	67 129	14.64	35 958	7.84
Goat	10 480	100.00	2 003	19.11	6 135	58.54	182	1.74
Sheep	7 981	100.00	1 542	19.32	3 682	46.13	34	0.43
Total	477 106	100.00	18 742	3.93	76 946	16.13	36 174	7.58

and kids during the first 46 weeks of their lives. The first milk to be let down, the colostrum, is of vital importance in survival of young not only as the only nourishment but also in the transfer, from the dam to her offspring, of passive immunity against some diseases.

Small ruminants are probably energetically more efficient as milk producers than are cattle on account of their prolificacy and short breeding cycle. It is possible that they are slightly more costly in terms of labour than cattle but with current opportunity costs of tropical labour in most areas this should not be too severe a restriction. Other advantages of small ruminant milk in the tropical context are the nature of production which can be staggered by planning breeding so that some milk is available all year round. Sheep and goats do not compete directly with cattle for feed and, particularly on smallholder farms, provision of feed is easier than for cattle.

Lactation Length

The genetic effects of breed type appear to be the only ones so far identified affecting lactation length. Coefficients of variation of the order of 25% among individuals (Fig. 9.14) indicate that some improvement in lactation length (Table 9.14) would be possible even in African indigenous small ruminant types. No environmental effects on lactation length have yet been identified.

Daily and Lactation Yields

Daily yields in sheep are affected by many environmental and genetic factors. One of these is

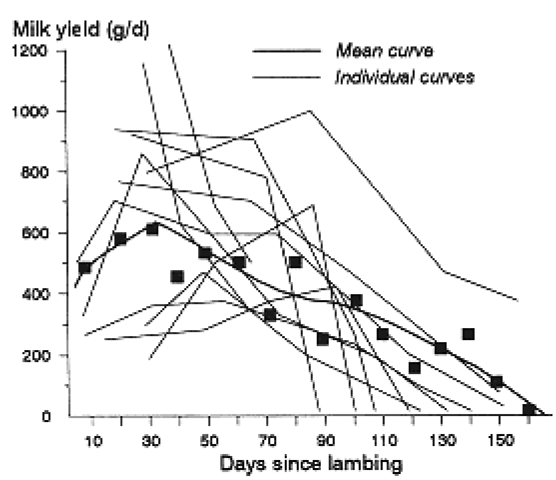


Fig. 9.14
Lactation curves of Macina sheep in central Mali
under simulated traditional management
(Source: Wilson, 1983.)

the sex of the lamb, female lambs extracting about 15% more than male lambs in Sudan (Sulieman & El-Tahir, 1984).

Awassi ewes under good management produce almost 250 kg of milk in a 200-day lactation (Gootwine & Goot, 1996). Unimproved Awassi sheep in Israel yield about 60 kg of milk but 11 better flocks recorded in 193738 averaged 131 kg per ewe while 77 recorded flocks in 196263 averaged 353 kg per ewe with the highest producer yielding 1050 kg (Epstein, 1977).

Transport

Sheep are used as transport animals in some areas. In Nepal rams of the Bhanglung and Bauwal breeds carry loads of 2.5 kg up very steep

Table 9.14 Milk production parameters and milk composition of tropical sheep.

Country	Breed type	Lactation details			Composition (%)				Source
		Length (d)	Daily yield (kg)	Lactation yield (kg)	Butter fat	Solids-not-fat	Protein	Lactose	
Sudan	Shugor	186		140	4.1	8.7			
	Dubasi	190		134	4.4	7.5			Suleiman & El-Tahir, 1984
Mali	Macina	135		50					Wilson, 1983
Ethiopia	Adal				4.1	9.5	4.4	3.7	Knoess, 1977
Israel	Awassi			60353	6.0				Epstein, 1977
India	(Various)			2030					Acharya, 1982
Indonesia	Priangan			2153	5.0				Atmadilaga, 1958

slopes at high altitudes and similar sheep are also used in India as pack animals. Some West African tribes use sheep to carry water for the herdsmen.

Constraints to Increased Productivity and Opportunities for Development.

Cattle have long been the species that has received by far the most research inputs. Sheep and goats, formerly of lesser importance to many tropical farmers, and of much lesser importance still to expatriate and Western-trained scientists, have been neglected. Increasing human populations, particularly in the medium and high potential mixed farming areas, are creating, and in many places already have created, a situation where large animals are no longer an economic or ecological proposition. Attitudes to small ruminant ownership are rapidly changing not least because it is being realized that a number of them can replace a single cow and provide a series of products more adapted to individual family needs and also because small ruminants have withstood the droughts of the 1970s and 1980s better than cattle.

There are exciting opportunities for improving reproductive performance by selection and crossing. Further improvements in reproduction may be possible in the future through the use of artificial insemination and embryo transfer but these techniques are not yet as well developed for sheep as they are for cattle. Considerable further research is required on heritabilities and genetic correlations of carcase characteristics. The evaluation of these parameters is of special importance for future national breeding and selection programmes. Wool is an important primary or by-product of the sheep industry. It has received less attention than it deserves in many tropical countries. In India and in South Asia in general, in West Asia and North Africa and in sub-Saharan Africa (Wilson, 1991) there are still unexploited opportunities and niches for wool production.

In spite of the increasing body of knowledge being accumulated on tropical indigenous small ruminants there is still need for much research adapted to the development needs of the livestock owners. Sheep productivity, perhaps more than that of any other domestic species, depends essentially on good managment. Simple management packages will perhaps yield best returns in the short term. These need to be coupled with adequate health interventions and the development of appropriate feeding systems based mainly on forages and crop residues and agricultural by-products. Genetic improvement, both of local breeds already well adapted to the environment, and of exotic and crossbreds of high potential productivity should be conducted in parallel and under both research station and farm conditions. Improved extension services and continuous monitoring of animal performance on farms are essential to the increased and sustainable output which is needed to supply the requirements of meat and milk for the tropics and to reduce the current drain on financial resources in most countries.

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10
Goats

Introduction

Goats have been considered, and still are by many, as of little or even negative value in contributing to human welfare and having a role in sustainable production systems. Goats are often found in severely degraded areas and are habitually accused of being the cause of degradation; seldom has any real effort been made to distinguish between cause and effect. Any degree of use of natural vegetation involves modificationsoften referred to as degradationto its composition. Where vegetative modifications occur there may be a gradual change in the combination of domestic ruminant species in favour of small ruminants and in particular of the goat. This is one of the main reasons why goats are blamed for desertification.

Small ruminants compete to some extent with other domestic species for some feed resources. They are, however, complementary to them with regard to the resources consumed and the height at which they are found. A higher total biomass of domestic livestock can thus be maintained, resulting in higher incomes from livestock production. The production of more than one species of domestic animal enables maximum use to be made of grass and browse across and within years. An illustration of the complementarity of the two major feed strata in the Sahel zone of Africa shows that the browse layer, such as *Boscia senegalensis*, is consumed by goats (87% of feeding time spent on the browse layer) and camels whereas sheep (59% of grazing time) and cattle graze on the annual grass *Schoenefeldia gracilis*. A mix of species makes it possible to reduce the overall stocking rate. On semi-arid rangelands in Kenya, for example, a stocking rate of 26 ha per tropical livestock unit (a TLU is equivalent to 250 kg liveweight) for cattle alone could be reduced to 13 ha/TLU when cattle and goats were reared together and to 10 ha/TLU when camels were included (Schwartz, 1983). In order to maintain these stocking rates, the ratio of one species to the other in terms of TLU should be 1.0:1.0:0.3.

Whatever the true state of affairs goats are a major species in, and an integral part of, tropical agricultural systems. In addition to quantifiable outputs of several products they are important for diversifying production, creating employment, increasing income, building capital, contributing to human nutrition and reducing risk. They are found in all agroecological zones from hyper-arid to super-humid and over the whole range of production systems from intensive smallholder production to very extensive nomadic pastoralism.

Interest in goat production in the tropics has burgeoned in recent years. This has come about with the realization that small ruminants in generaland goats in particularare an underused and poorly understood resource. A fuller understanding of their role, capabilities and outputs cannot but help them further to contribute to the overall productivity of tropical farming systems.

Origins and Ancestry

Goats belong to the tribe Caprini in the sub-family Caprinae of the family Bovidae in the

Fig. 10.1
Nubian ibex, *Capra ibex*, in captivity at Khartoum zoo, Sudan.

suborder Ruminantia of the order Artiodactyla. They are typical cloven-hoofed ruminants of relatively small size. The Caprini comprises five genera. Two of these, *Capra* and *Hemitragus* are true goats; one genus, *Ovis*, is the sheep; and there are two genera, *Ammotragus* and *Pseudois*, of goat-like sheep and sheep-like goats.

The most recent taxonomy divides the two genera of true goats into three species of *Hemitragus*, or tahrs, and six of *Capra*. All the tahrs have the same chromosome number ($2n = 48$). Most *Capra* species are interfertile although for some pairs no crosses are recorded; all the species examined (bezoar *C. aegagrus*, ibex *C. ibex* and markhor *C. falconeri*) have the same number of chromosomes ($2n = 60$).

It is most likely that only bezoar blood, of the six species of *Capra*, is present in the modern domestic goat. There is, however, a slight possibility that the markhor may have been involved in the ancestry of some Indian breeds. The ibex (Fig. 10.1) has several subspecies in Europe, Central Asia, the Near East and Africa but does not seem to have been involved in the descent of the domestic goat which, to distinguish it from the wild types, is classed as *Capra hircus*.

Domestication

Goats were almost certainly the first ruminant to be domesticated (Devendra & Nozawa, 1976) and were possibly only the second species to be taken into the human fold after the dog (Zeuner, 1963). Present day Iran and Iraq in West Asia is the most likely area of origin of the domestic species as the bezoar *C. aegagrus* is present there. From its centre of domestication it probably first spread eastward into Central and Southeastern Asia (Fig. 10.2). Domestication occurred gradually over a period beginning some 11 000 years BP (before present) but centred on about 9000 BP (Mason, 1984). Goats had moved into sub-Saharan Africa by at least 5500 BP and a dwarf type is recorded from that period near Khartoum in Sudan.

Numbers and Distribution

In the mid-1990s the world population of goats was estimated at about 610 million, of which about 94% were in tropical and subtropical areas (FAO, 1995).

About 30% of tropical goats are found in Africa (Table 10.1) where they are concentrated in the arid and semi-arid regions of Western Africa, Sudan, the Horn of Africa and Eastern and Southern Africa. In these dry areas increases in the goat population of almost 30% took place from 1980 to 1994 and they are here second only to cattle, of the herbivore species, in numbers. Goats are less numerous but also an important element of the species mix in the drier areas of Southern Africa. There are few goats, or indeed any domestic species, in West-Central Africa but small trypanotolerant types are common and more numerous than other domestic livestock in the humid tsetse-infested areas of coastal West Africa and its hinterland.

About 50% of tropical goats reside in Asia. South Asia is an important area for goats and contains about 30% of the tropical population of the species. Here they are concentrated in the arid to semi-arid densely populated areas of the central highlands and in the mountainous regions of the north. West Asia also has large numbers of goats amounting to about 15% of tropical numbers. There has been much interest in small ruminants (goats and sheep) in research and development circles in recent years in Eastern Asia, in Central America and the Caribbean, and

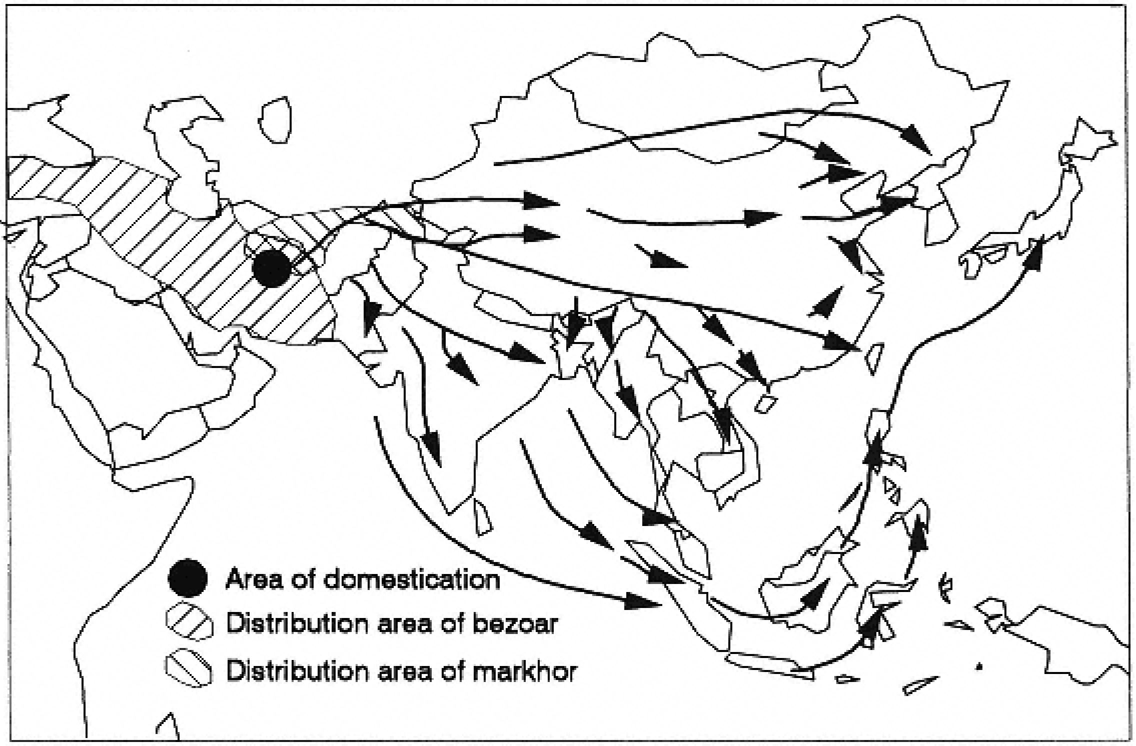


Fig. 10.2
Area of domestication and subsequent spread of goats in Asia.
(Source: Devendra & Nozawa, 1976.)

in South America but goats are found here in low numbers, at low densities and at low goat to human ratios; they represent only 4, 3 and 5%, in the three areas, of the total tropical population.

Goat numbers increased by 35.0% in the tropics in 198094. In Africa the increase was 29%, in South America 23% and in Asia a huge 35%. The increase in Asia probably results largely from economic growth and changes in dietary preferences and habits of the people there.

Types and Breeds

Types

There have been several attempts to assign goats to types based on such variables as origin, utility, body size, ear shape and ear length. One classification for the tropics (Devendra & Burns, 1983) is based on body size and comprises large (>65 cm at the withers), small (5165 cm) and dwarf (<50 cm) types. Another classification that does not appear particularly useful divides goats into long-eared and short-eared types (Mason & Maule, 1960). Classification of tropical goats by function has not, so far, found a great deal of support. This is perhaps because goats indigenous to the tropics have been selected mainly for survival. There has, therefore, been little differentiation into major types related to production objective or function and most tropical goats are used as a source of meat. One or two breeds, notably the Red Sokoto or Chèvre rousse de Maradi of northern Nigeria and Niger and the Mubende of Uganda, are also reputed as producers of high quality skins. There are a few types with good milk potential.

Large goats, that may also have legs that are disproportionately long as an adaptation to aridity (Fig. 10.3), are found in West Asia, South

Table 10.1 Numbers, density and ratio to humans of goats in some selected areas and countries. (*Source*: adapted from FAO, 1995.)

Continent/country	Number (000)	Density (No./km2)a	No./personb
Africa	176 089	5.942	0.427
Botswana	2 475	4 .367	2.861
Burundi	850	33.010	0.151
Congo	305	0.893	0.208
Ethiopia	16 700	16.700	n.a.
Kenya	7 438	13.069	0.362
Mozambique	389	0.496	0.031
Niger	5 900	4.658	0.781
Nigeria	25 497	27.94	0.371
Somalia	12 000	19.239	1.937
Togo	2 048	37.654	0.750
Zaire	4 317	1.904	0.160
Asia	373 005	13.923	0.203
Bangladesh	28 050	215.487	0.362
India	118 347	39.805	0.210
Indonesia	12 281	6.779	0.154
Laos	153	0.663	0.046
Pakistan	41 340	53.627	0.594
Philippines	2 800	9.391	0.095
Sri Lanka	500	7.736	0.054
Syria	1 200	6.530	0.388
Yemen	3 232	6.122	0.435
South America	22 819	1.302	0.339
Bolivia	1 517	1.399	0.533
Brazil	12 200	1.443	0.349
Ecuador	345	1.245	0.112
Peru	1 713	1.338	0.212

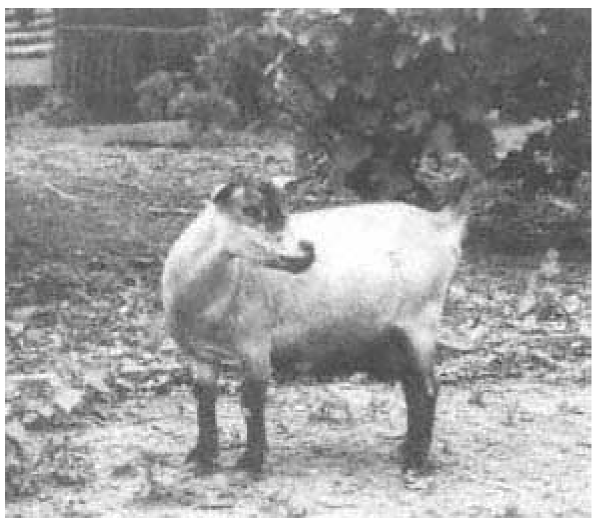
Venezuela	1 850	2.097	0.959
World	609 488	5.551	0.249

n.a. = not available.
a Area used to calculate density is total land area.
b Figure used to calculate ratio to people is total agricultural population.

Asia, China and Southeast Asia and in Africa along the southern fringe of the Sahara and also in Southern Africa; they have also been imported into the Americas. Small types, 5165 cm at the withers, are found in Asia in the same areas as the large types but in Africa they are mainly distributed in the northeast and eastern areas. Small goats are also found now in the Caribbean and Central and South America as well as Oceania. So-called dwarf types with withers heights of less than 50 cm are found in parts of South Asia, in southeastern China and in Northeastern and Eastern Africa. True dwarf goats of the achondroplasic type (which are also to some extent tolerant of trypanosomosis) are found mainly in humid West Africa (Fig. 10.3).

In addition to meat, skins and milk are the major products of goat production. There have been many attempts to improve indigenous goats by outcrossing to temperate breeds for milk, meat or fibre production. These specialist types are being increasingly used in modern intensive and semi-intensive systems and in traditional and

Fig. 10.3
Desert-adapted and humid-zone adapted goats from
Burkina Faso (West African Long-legged)



Ghana (West African Dwarf) in Africa.

improved traditional systems. Projects of this kind have often shown some success whilst there was external support but many have failed in the long term except in cases where artificial conditions have been created for the pure exotics and for backcrosses beyond the F1 generation.

Breeds.

Most tropical goats are little differentiated and may justifiably be called nondescript. It is, however, possible to identify many breeds (Table 10.2) on the basis of physical, morphological and functional characteristics and more than 350 have now been named. Many of these have been reviewed and described fully elsewhere (Mason, 1981; Devendra & McLeroy, 1982; Devendra & Burns, 1983; Wilson, 1991b). A recent comprehensive survey of goats in Ethiopia identified 14 'clusters' of breeds based almost entirely on morphological characters (FARM-Africa, 1996). It appears that only the Boer in Southern Africa and the Damascus in the Near East (and especially Cyprus) of the true tropical or near-tropical breeds have been the subject of concerted long-term breeding programmes (Fig. 10.4). The Boer is now in great demandat very high pricesin New Zealand and Australia as a means of diversifying the production base.

Many tropical breeds are as potentially valuable as temperate ones for raising the productivity of other tropical types for meat, milk, skins or fibre, not only directly but through their prolificacy or short kidding intervals. Tropical breeds capable of producing 1.33.0 kg of milk daily include Damascus, Barbari, Malabari and Jamnapari from India, Dera Din Panah and Kamori from Pakistan and Nubian (Fig. 10.4) from the Nile banks of Sudan and Egypt. Of the meat goats the Boer is outstanding as females weigh as much as 75 kg and mature castrates scale in at 100 kg without supplementary feeding.

Goats in China (Fig. 10.4) are reputed as producers of cashmere. Mohair is a valuable product of Angora goats in many areas with tropical type climates but this breed is fast disappearing from its centre of origin on the Anatolian Plateau in Turkey. In Pakistan the small Teddy has become widely distributed and popular since the 1980s, produces about 50% of twins and is justifiably renowned for its prolificacy.

Some progress has been made in establishing genetic differences among breeds and populations of goats. In four Southeast Asian

Table 10.2 Some major goat breeds and production functions in the tropics.

Country/area	Breed name(s)	Production function(s)
China	Banjiao, Chengdu Ma, Duan, Fuying, Guizhou White, Haimen, Huaipi, Leizhou, Longlin, Matou, Shanxi White	Meat (and many for cashmere)
India	Beetal, Jamnapari, Marwari	Milk
	Black Bengal, Malabari	Prolificacy
	Chigu, Changthangi, Jhakrana, Osmanabadi, Sangamaneri, Sirohi	Meat
	Barbari	Milk, meat, prolificacy
Pakistan	Beetal, Dera Din Panah, Kamori, Damani	Milk
	Bikaneri, Chappar, Damani, Gaddi, Kaghani, Kajli	Meat
	Teddy	Prolificacy
Nepal	Chyangra, Sinhal, Khare, Terai	Meat (+cashmere for first two)
Fiji	Fijian	Meat
Malaya/Indonesia	Katjang	Prolificacy
Western Asia	Damascus (Shami)	Milk
	Syrian Mountain, Black Bedouin	Meat
Saudi Arabia	Ardhi	Meat, milk
Egypt/Sudan	Zaraibi, Nubian	Milk
Maghreb	'Tunisian' (plus other 'national') Black	Milk, meat
African Sahel	Long-legged Sahel, Sudan Desert	Meat, milk
West Africa	West African Dwarf (several synonyms and local types)	Meat (skin eaten with meat)
Nigeria/Niger	Red Sokoto (= Chèvre rousse de Maradi)	Skin, meat, milk
Horn of Africa	Galla (= Boran, White Somali)	Meat, milk
East Africa	Small East African (several local types Masai, Kigezi, Burundi, Tanzania, Malawi, Shona)	Meat
Southern Africa	Tswana, Swazi, Ndebele, Landim	Meat
	Boer	Meat, milk, 'improver'
Caribbean and Central America	Criollo	Meat
Brazil	Moxoto, Brazilian, Bhuj	Meat, milk

countries (Indonesia, Malaysia, Philippines and Thailand) large samples of nine populations were examined by cellulose acetate and starch gel electrophoretic techniques for coding of 26 loci of blood proteins and enzymes (Selvaraj *et al*., 1991). A dendrogram constructed from the results showed that the nine populations grouped into one cluster of five and two clusters each of two populations with the only country cluster comprising Bogor and Ujung Padang populations from Indonesia. It was suggested that isolation had resulted in genetic drift which could also be expected to result in differences in genetic merit for growth and other production traits.

Genetic Modification

Many attempts have been made to improve indigenous tropical goats by outcrossing to temperate types for milk, meat or fibre production. Outstanding among the European 'improver' breeds are the Alpine, Anglo-Nubian, Saanen and Toggenburg (the last sometimes known, especially in Malaysia, as the 'Improved German Fawn'). Demandnot always rationalhas been such that the quality of some goats exported from Europe to the tropics has not always been the very best and has led to some disappointing results. The Anglo-Nubian is probably the most

Fig. 10.4
Boer goats in South Africa

Damascus goat in Cyprus

Nubian goat on the Nile

Cashmere types in China.

widely distributed of the temperate breeds and it has generally performed better than the others both as a purebred and a crossbred and for meat as well as milk. In Malaysia highest mature body weights were obtained from 3/4 Anglo-Nubian × 1/4 local but the F1 generation was the best milk producer with a yield of 296 kg in 235 days. In Trinidad yields of 34 kg/day have been obtained but in the Philippines yields were only 12 kg. Saanen goats are preferred for milk elsewhere including Australia, India, Kenya, Israel, Venezuela and the West Indies.

The Saanen is particularly vulnerable to problems if it is not provided with shade. This is but one example of the special care, involving additional expense, that often has to be provided if exotic breeds are to compete in the tropics. Many attempted introductions have failed (see section on Productivity) to outperform local types other than in cases where artificial conditions have been created for the purely exotic types and the progeny of the crossing programme. As already mentioned possibilities for improving milk or meat production exist by the use of some tropical breeds such as the Jamnapari and Beetal of India, the Boran (or Galla) of northern Kenya or the Boer of Southern Africa.

Adaptation

The goat is adapted to a wide spectrum of ecological zones, from hot and cold dry areas to humid tropical ones. The species has a great ability to select from a wide range of feed sources especially at times of a general shortage of high quality fodder. This strategy compensates for low reserves (rarely exceeding 15%) of body fat. especially compared to sheep (Table 10.3) and cattle. Goats lay down little fat under normal nutritional status. When they are in exceptional condition as a result of good feed supplies, the small amount of fat they do store is mostly in the viscera and around the kidneys. Sheep and cattle lay down much more fat (as high as 40% of carcase weight) as a strategy against seasonal fluctuations in feed supply. The goat does suffer, however, if it has inadequate access to browse of

Table 10.3 Fat content (%) in carcases of different age classes of Botswana goat and sheep castrates. (*Source*: Owen *et al*., 1978.)

Age class	Species	
	Goats	Sheep
Temporary incisors	10.8	21.2
Permanent incisors		
1 pair	10.6	22.5
2 pairs	12.1	22.8
3 pairs	14.8	27.5

high quality. Desert goats are better adapted to poor quality diets than non-adapted ones and also eat less in relation to body weight. Lower feed consumption in desert-adapted goats is due to a lower basal metabolic rate (Shkolnik *et al*., 1972). Digestibility of feed is higher in adapted than in non-adapted goats and the former are more efficient at nitrogen conservation.

Goats are able to replace lost water rapidly at a single drinking. Intake can be up to 45% of body weight without haemolysis occurring (Shkolnik *et al*., 1972; Maltz & Shkolnik, 1980). This peculiarity is tied to the role of the rumen as a water store. Unlike the camel the water does not pass immediately to the blood and other tissues but remains in the alimentary tract for some time. The controlled flow of water from the rumen to the lower and permeable part of the gut, where it is absorbed into the tissues, allows blood parameters to be maintained at near normal levels to avoid overhydration and haemolysis (Choshniak *et al*., 1984). No increase in urine flow follows on this relatively massive intake of water; there is, indeed, a decrease (probably in order to conserve the water that has been drunk) and a rate of flow equivalent to that of the dehydrated animals is not regained for 4 hours. Low rates of urine flow following rehydration have been noted in Merino sheep (Blair-West *et al*., 1972, 1979) and in cattle and camels (Siebert & Macfarlane, 1975) but low rates in cattle were transient. In desert-adapted goats periodic water shortage has short-term effects on milk yield which is reduced towards the end of the deprivation period but recovers when water is again made available.

Goats sweat and pant less than sheep. A major strategy for reducing the heat load is a high skin temperature that allows heat to flow from the body to the environment down the resulting negative gradient. When necessary, however, goats can tolerate some rise in body temperature with only minimal effects on feed intake and normal activity patterns. During evolution the activity of the desert goat's thyroid gland has been reduced, thus lowering the rate of heat production. Other adaptations of the goat include the body shape, which is often angular with long legs in the arid regions (to avoid heat absorption of long waves reflected from the ground and reducing exposure to the sun's direct effects), and short and dwarfed in the humid regions (Fig. 10.2).

The horns of goats may also have a role in maintaining the internal body temperature as these are the only superficial areas with a major drainage of blood through the cavernous sinus (Taylor, 1966).

Most goats have thin supple skins and short fine hair and many desert breeds are light coloured. There is some evidence, at least in Africa, that pastoral tribes are aware of the advantages of light coat colours and actively select for them. In a study of cattle in Kenya (Finch & Western, 1977) a linear relationship ($y = 0.07x$ 73.9 where y was the percentage of light coloured animals and x the potential evapotranspirationin this case used as a proxy for heat stress) was shown between the proportion of light-coloured animals and the level of environmental stress.

There are, nonetheless, many and zone goats that are dark in colour. One is the Red Sokoto of northern Nigeria and southern Niger. The most widely known goat in this respect is, however, the Black Bedouin of the Negev and Sinai deserts in West Asia. Since scientific attention was originally brought to the apparent anomaly of a black goat in a desert (Shkolnik *et al*., 1972) much has been written although most published work relates to water economy rather than, strictly speaking, to temperature regulation (Choshniak & Shkolnik, 1977, 1978; Finch *et al*., 1980;

Choshniak *et al*., 1984; Shkolnik & Choshniak, 1985; Choshniak *et al*., 1987). Theoretical considerations lead to the conclusion that the black colour would be a disadvantage in an intense radiant environment. As black goats are the commonest domestic animal in the Negev and Sinai deserts (they are also common in many other desert areas, including Syria, Lebanon, Tunisia, Morocco and Sudan) the possibility was considered that the black coat might be an adaptation to the desert environment.

Experiments were undertaken on black goats, a white goat from the same environment and a female ibex (*Capra ibex*). The ibex is basically fawn in colour. The results showed that on full exposure to the sun the net heat gain of black goats was considerably greater than that of both the white goat and the ibex. There were no differences in metabolic heat production or heat storage among the three types of animal and all the additional heat gained by the black goats was lost through evaporation. There were no differences in heat balance when all animals were confined in the shade. The difference in heat gain in sunlight was due almost entirely to short-wave (0.32.5 m) absorption this being almost twice as much in black goats (288 W/m2) when compared to white goats (153 W/m2) or the ibex (158 W/m2). Long-wave radiation (>2.5 m) was absorbed in similar amounts (»460 W/m2) by all three groups.

Black goats do not, therefore, have a comparative advantage in thermoregulation at hot temperatures. It is then suggested that there are advantages to these goats in the winter, when they warm up earlier and more quickly than light-coloured goats. Similar advantages, leading to lower death rates following drought and starvation, have been postulated for black over white cattle in Kenya (Finch & Western, 1977). It has, however, been rather surprisingly shown that under the black burnous worn by Bedu the temperature does not differ from that under white robes in spite of much higher outer garment temperatures (Shkolnik *et al*., 1980).

In another study of black goats in India in the winter (Goyal & Ghosh, 1987), albedo measurements showed an absorption of about 82% of the incident radiation which was calculated at from 656 to 815 W/m2 for four goats. This value is similar to the one found for Sinai goats but in India heat gains were only 3056 W/m2 or about 6.3% of the heat falling on a horizontal surface. It was concluded that in black goats most of the incoming heat was re-radiated at or near the coat surface as long-wave radiation.

The major advantages of including goats and, to a lesser extent, sheep in mixed species groups are evident during a prolonged period of drought. The two species of small ruminants appear to withstand drought better than cattle although there are regional and breed variations with regard to the ability to do so. The Masai of Tanzania and Kenya are generally considered to be cattle breeders but the importance of goats and sheep (Table 10.4) is clearly emphasized by the number of people who keep them and was clearly of importance following a drought in the

Table 10.4 Effects of drought on livestock numbers in a Masai system at Loitokitok, Kenya. (*Source*: Campbell, 1978.)

Item	Species		
	Cattle	Sheep	Goats
Percentage of families owning	60	80	90
Group size before drought	84	27	41
Sales	11	2	5
Deaths	25	9	8
Group size after drought	48	16	28
Percentage of original animals after drought	57	59	69

mid-1970s (Campbell, 1978). The resumption of breeding by these two species following a drought guarantees food in the form of milk even before cereals can be harvested.

Reproduction

Male

Puberty has been defined as the age at which spermatozoa appear in the ejaculate. Based on this definition male goats reach puberty at 97 days in Thailand and reach sexual maturity, indicated by live spermatozoa in the ejaculate, at 132 days which is about the same time (122 days) that complete separation of the urethral process occurs (Suttiyotin *et al*., 1991). Weight at puberty in this group of animals is only 30% of final liveweight. Bucks of 5 months of age have only half the epididymal sperm reserves of 5-year-old males mainly because reserves in the caudal portion are very low at the younger ages.

Bucks ejaculated repeatedly over a period of 8 hours have a reduced total ejaculate volume, reduced spermatozoa concentration per ml of ejaculate and, evidently, reduced total numbers of spermatozoa. The number of spermatozoa could fall below that required for fertilization after the sixth ejaculate, especially in hormonesynchronized does in which large numbers are required to overcome the associated reduced transport in these females (Murugaiyah & Abdul Wahid, 1991).

Female

Female goats in Thailand often conceive as early as 4 months (Suttiyotin *et al*., 1991). Puberty is related more closely to mature weight than to age, however, and usually occurs at about 6070% of adult weight (Devendra & Burns, 1983) which is relatively later than in males. Physical maturity is therefore closely linked to growth rate with the fastest growing animals achieving sexual maturity earlier than slower growing ones. It is common in the tropics for goats to reach sexual maturity at 46 months but so-called modern management practices are often designed to delay mating until females are closer to mature body weights so that pregnancy does not interfere with the growing and physical maturation processes. No such practices are employed in most tropical traditional systems and there is no evidence that animals mated early suffer any ill effects.

The duration of the oestrus cycle in goats is similar to that of sheep in the general range of 1821 days. Oestrus seems to last somewhat longer than for sheep, however, at 2436 hours although there is considerable variation. Ovulation occurs towards the end of oestrus and this is the best time for mating; as time of mating can affect the number of kids born, double mating may be advantageous although this undoubtedly occurs naturally in most tropical production systems. Gestation length is usually in the range 145148 days and has been found to average about 146 days for several tropical breeds; this may be slightly shorter than the gestation period of tropical sheep.

Oestrus occurs all year round in most truly tropical goats. Most evidence suggests that differences between tropical and temperate breeds in a tropical environment are related to breed rather than to climate or daylength. It is possible, however, that temperate breeds of goats take a very long time to adapt their breeding cycle to tropical conditions. This results in annual kidding being characteristic of purebred temperate breeds in the tropics (as well as of a few tropical and subtropical breeds) which may mean that genetic factors are more important than environmental ones in these breeds. There seem to be tendencies in all goats, however, for the incidence of oestrus to be higher at certain times of the year. In India, for example, it is highest in June to October and in the Caribbean and Venezuela in August to September.

Climatic factors and their effects on feed availability may be involved in this seasonal phenomenon although they should have less influence in goatswith their wider dietary preferencesthan they do on animals which rely more on grazing for their feed, such as cattle and sheep. In Thailand there is a peak in the number of conceptions in the rains in October to December.

Some support for the effects of climate on reproductive performance is provided by some studies that have shown a significant correlation between total annual rainfall and the percentage of does kidding or of kids born. Meat breeds may also have a shorter kidding interval than milk breeds presumably due to the influence of lactation. In India and Malaysia, for example, native goats have shorter intervals between kiddings than the 327 days and 204 days of purebred and crossbred Anglo-Nubians. As for sheep, two kiddings per year are possible but in practice this level of performance is seldom achieved.

Breeding Methods and Practices

The main breeding methods employed in goats are selection within indigenous breeds and crossbreeding. Selection within indigenous breeds is essential in order to understand their potential. It is only when this has been completed and the need for further improvement justified that crossbreeding should be undertaken. Crossbreeding experiments must also be undertaken in the same environment and under the same conditions as for the native breed. Knowledge of the heritability and repeatability of various traits is essential in deciding whether or not any particular trait should be included in the breeding objectives and among the selection criteria.

Efforts to improve overall reproductive performance are often concentrated on the female component of the flock. It needs to be remembered, however, as the old British farmers and breeders used to say 'the male is half of the herd'. Ensuring that male animals get adequate attention and feed, especially before and during the breeding season will therefore contribute much to ensuring that overall reproductive performance is maintained at a satisfactory level. A period of 6 weeks is required for spermatozoids to mature. Breeding bucks in poor condition therefore need to be fed a high protein diet starting at least 8 weeks before being introduced to their respective groups of females if reproductive wastage is not to occur. Infertility in male animals may arise from infectious epididymitis caused by *Brucella ovis* and *Actinobacillus seminis*.

Reproductive Performance

Age at First Kidding

The variation in age at first kidding is from as young as 7 months (conception at 2 months!) to as old as 2 years (Table 10.5). In most areas where breeding is uncontrolled most goats have conceived by 7 months and had kids at or before 12 months. In Thai goats, for example, average age at first kidding is 12.4 months with 60% of females conceiving before 7 months and 7% at 34 months. West African Dwarf goats and many other African breeds give birth to their first kids at 1218 months. In general there appears to be very little advantage in trying to

Table 10.5 Major reproductive parameters of goats in the tropics.

Breed	Country	Reproductive parameter			Source
		Age at first kidding (months)	Kidding interval (days)	Litter size (No. of lambs)	
Barbari	India		238		Bhattacharyya, 1988
Beetal	India		346		Bhattacharyya, 1988
Black Bengal	India		224		quoted in Bhattacharyya, 1988
Jamnapari	India		306407		quoted in Bhattacharyya, 1988
Malabari	India		299		quoted in Bhattacharyya, 1988
Marwari	India	18.0			Acharya, 1982
Alpine	Mexico	14 ± 2	345 ± 75	1.69 ± 0.5	Silva *et al*., 1998

delay first parturition in goats (and in sheep). Early first parturitions do not result in lowered lifetime production of viable young, despite higher mortality in kids born of young does, and may lead to higher production because an additional later parturition will produce a larger litter size than the small one of the primiparous doe (Wilson, 1989).

Kidding Interval.

Kidding intervals in most tropical goats vary in the range 180300 days (Table 10.5) although there is wide variation from a physiological absolute lower limit of about 150 days to more than 550 days. In the Alexandria region of northern Egypt kids are born throughout the year, with peaks in April and November, but kidding intervals are slightly in excess of 12 months (0.96 kiddings per doe per year). Most reports and studies of kidding intervals in West African Dwarf goats indicate an average interval of about 210230 days in traditional systems but one study of an institutional flock over a 10-year period showed intervals to be 275 days (Odubote, 1996).

Litter Size

Twin births are common in goats and larger litter sizes are not rare. Factors which influence litter size include the season and year of mating, nutritional status and weight of the doe. There is a good deal of evidence that prolificacy or litter size increases with parity or age before levelling off. In Malabari goats in India, for example, the proportion of twin and triplet births increased from 19% at first kidding to 79% in later kiddings. In Negev and Saanen goats in Israel the number of kids increased from 1.1 and 1.5 at first kidding to 1.5 and 2.0 at subsequent parturitions. A similar increase takes place in Baladi goats in Egypt. Within the Southern African region the improved Boer goat in the Republic of South Africa, with a litter size of 1.64 in intensively managed flocks (Skinner, 1972), is comparable but data from outside the Republic of South Africa where the Boer goat has been introduced, indicate much smaller litter sizes. West African Dwarf goats of the central and west African humid zones also have large litter sizes (Bourzat, 1985). Thai village goats have similar reproductive performance to the Katjang of Malaysia (Saithanoo *et al*., 1991); kidding rates in goats of less than 1, of 12 and of more than 2 years are 131, 194 and 208% and are higher in village systems than in managed single-mating systems because of the multiple opportunities for breeding.

West African Dwarf goats are noted for their prolificacy. Goats of this breed at Ile-Ife University in Nigeria had a litter size of 1.79 ± 0.05 (SE) kids over a 10-year period (Odubote, 1996). Percentages of single, twin, triplet and quadruplet births were 37, 53, 9 and 1, respectively. Litter size was affected by the age of the dam and her parity (although there is obviously some confounding here) with a progressive increase in the number of young per parturition to the seventh parity. Heritability ($h2$) estimates for litter size were 0.35 ± 0.05 which indicates that a high response to selection for this trait could be expected.

Annual Reproductive Rate

As for sheep, the number of young produced per year is an important parameter in overall reproductive performance and total productivity. Maximum production of young per year seems to be at 56 years, after which the kidding interval begins to lengthen and the litter size decreases. The number of young per parturition (litter size) is not always greatest, and indeed may be smallest, at the period that most births are taking place (Fig. 10.5). This is probably because the first flush of new feed is sufficient to give a boost to the physiological processes of reproduction but even better nutritional status is needed for the number of eggs that are shed to be increased (Wilson & Sayers, 1988). The time of mating therefore has an important effect in the annual reproductive rate especially where intra-year climatic variations are great and there are likely to be periods of plenty alternating with periods of deficit.

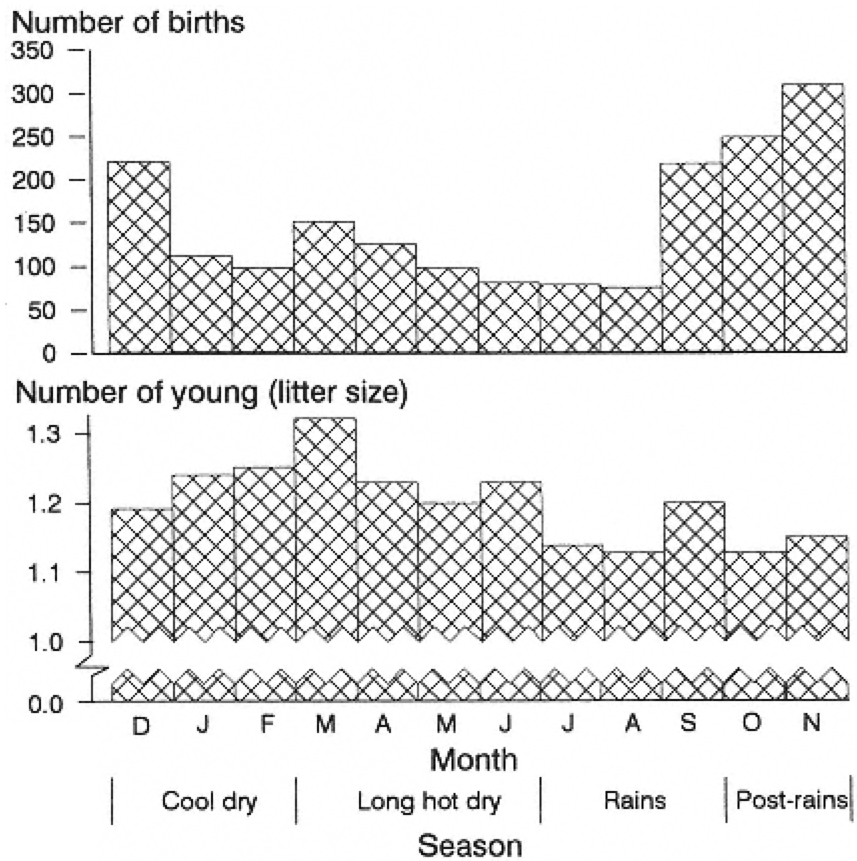


Fig. 10.5
Seasonal effects on number of parturitions and litter size in goats in an agropastoral system in central Mali.
(Source: Wilson & Traoré, 1988.)

Chinese goats are prolific and have kidding rates of 1.22.7 young per doe per year. In Africa the annual reproductive rate of goats under traditional management averages 1.46 over many studies and varies in the range 0.981.97 (Wilson, 1989). In Indonesia the Ettawah and Bogor breeds produce 3.09 and 3.68 offspring per year (Obst *et al*., 1980). These are just some examples of the potential for high reproductive performance in tropical goats which compare very favourably with or are even better than those of goats in temperate regions.

Goats usually show better overall reproductive performance than sheep and this often leads to slightly better overall production. The differences are rarely well enough differentiated to lead to a recommendation that one species should be preferred over the other. It is possible that maintaining a mix of the two species leads to better use of feed resources and greater overall animal production from a unit area than from keeping one species alone.

Reproductive Wastage

The reproductive performance of tropical small ruminants, especially in traditional systems, is generally considered to be less than optimal and wastage is also thought to be high. The components of reproductive performance are similar to those found elsewhere and include age at first parturition, intervals between successive parturitions and total number of young produced per female life. Reproductive wastage is here defined to comprise embryonic loss, perinatal losses and postnatal losses to the time of first parturition (Lebbie *et al*., 1996). Slow growth rates due to poor and fluctuating nutrition often cause wastage by delaying puberty. Long intervals between successive births, which also appear to be related largely to nutrition, are a further source of loss of reproductive potential. Females of breeding age that are slaughtered for short-term financial reasons during pregnancy constitute a further source of loss.

Sound health and the ability to breed regularly result in an animal producing the maximum possible number of young in its lifetime. Reproductive disorders and diseases associated with, or linked to, the reproductive process reduce breeding efficiency and limit opportunities to improve the quality of stock or to increase economic returns. A thorough knowledge of the likely health problems associated with reproduction and how to overcome or minimize them contributes to overall farm profitability.

The major reproductive problems of goats and of small ruminants in general include abortions, stillbirths, agalactia, mastitis, metritis, dystocia and perinatal mortality (Smith *et al*., 1988). Many are associated with systemic diseases that lower overall performance while others cause fetal mortality, abortion or male infertility. Fetal mortality and abortion can be due to clearly identified causes including vibriosis (*Campylobacter fetus intestinalis*), salmonellosis (*Salmonella abortus-ovis* and *S. dublini*), *Listeria monocytogenes*, chlamydia, ticks (*Ixodes ricinus*) that carry tick-borne fever, Border disease, 'Q' fever (*Coxiella burnetti*) and *Toxoplasma gondii*. Brucellosis or contagious abortion is a specific disease of reproduction that is usually caused in goats (and sheep) by *Brucella melitensis* but occasionally by *Brucella abortus*. Temporary or permanent sterility are also consequences of the disease which can be spread by contaminated feed and water as well as through bodily discharges and via the milk. The disease is an important zoonose and can be transmitted to man by direct contact or via the milk. In man it is known as undulant fever because of the transient high fever it causes. Non-specific causes of abortion are congenital or acquired, due to poor management, poor nutrition or climate conditions. Other factors involved are general weakness and starvation as well as chemical and plant poisoning. Abortions may be more common in multiple pregnancies and stillbirths are certainly higher in twin and triplet pregnancies than in single pregnancies. Abortions are also usually more common in goats than in sheep.

Mortality before birth is often difficult to establish and to calculate. The definition of life (i.e. the beginning of life) varies and, depending on that definition, may be considered to start at conception, at implantation, at the blastocyst stage, or at a variety of other stages of development (Wilson & Traoré, 1988). Perinatal or neonatal mortality, a commonly adopted definition which includes late abortions, stillbirths and deaths within 1, 2 or 7 days of birth, can be due to abortion, stillbirth, starvation or exposure, infectious diseases, congenital defects, predators and accidental death or loss.

Nutrition

Goats are intermediate feeders tending towards concentrate selection (van Soest, 1982). They are essentially browsers that feed mostly on the leaves, flowers, fruits and twigs of shrubs and other ligneous plants. They will, however, eat grass and herbs when there is no alternative. Goats have very eclectic tastes and select their feed from a wide range of plants. Their narrow mouth parts enable them to be very selective, however, in the parts of plants that they eat. For this reason they cause little damage to the plant structure unless the vegetative biomass is already greatly reduced. The ability to distinguish among bitter, sweet, salty and sour tastes is a further peculiarity of goats. The bipedal stance often adopted by goats when feeding further adds to their competitive advantage over sheep. More information on goat nutrition and feeding is available in Haenlein (1980) and National Research Council (1981).

Physiology

As with the other common domestic herbivores the fore-stomach volume of the goat increases during dry periods. This allows more feed to be eaten without the concomitant problem of a reduced retention time in the rumen. Retention times of fluid and small particles have been shown to be longer in the dry season than in the wet season as a result of increased fore-stomach volume (Lechner-Doll *et al*., 1990). The increased retention time also has the effect of increasing the digestibility of the feed (Table 10.6). Increases in all of volume, retention time of fluid and particles, and digestibility are, however, smaller in goats than in the less selective sheep and cattle and indicate the ability of the goat to maintain a diet quality that is higher than the average of the total feed on offer.

Table 10.6 Increases (%) in fore-stomach volume, fluid and small particle retention times, and digestibility of diet in four ruminating species in Kenya in the dry compared to the wet season. (*Source*: Lechner-Doll *et al*., 1990.)

Species	Fore-stomach volume	Fluid	Small particles	Digestibility
Camel	28.0	35.2	17.9	8.0
Cattle	39.3	56.8	27.3	7.0
Sheep	55.2	74.8	46.1	12.0
Goat	28.9	40.7	22.0	6.0

Feed Preferences

Goats have relatively less rumen volume to body weight than specialized grazing animals and are classed as intermediate feeders, tending towards selection of high quality diets, with a preference for browse when available. When herded together with sheep the latter are often encouraged to do likewise. The phenology of several species of browse is such that leaves and fruits with a high protein content are available during the dry season. The nutritional needs of small ruminants are consequently less restricted by the seasons than those of cattle or buffaloes. This is reflected in their ability to maintain their weight to within a few per cent of their annual average as compared to cattle (Fig. 10.6). The less marked seasonality of breeding compared to cattle is probably also related to nutritional status.

Although goats are more selective than cattle or sheep in diet quality they have eclectic tastes and feed on a wider range of plants than any other species except the camel with which they also have the greatest similarity of diet. Dietary overlap between goats and camels in Kenya is almost 50% in the dry season (Schwartz, 1983) but is as little as 12% in the wet season when goat diets are more similar to those of sheep (Fig. 10.7). Goat diets are more dissimilar to those of cattle at all seasons than they are to those of other species, including the donkey.

More than 60% of feeding time, and on occasions as much as 90%, is spent by goats on

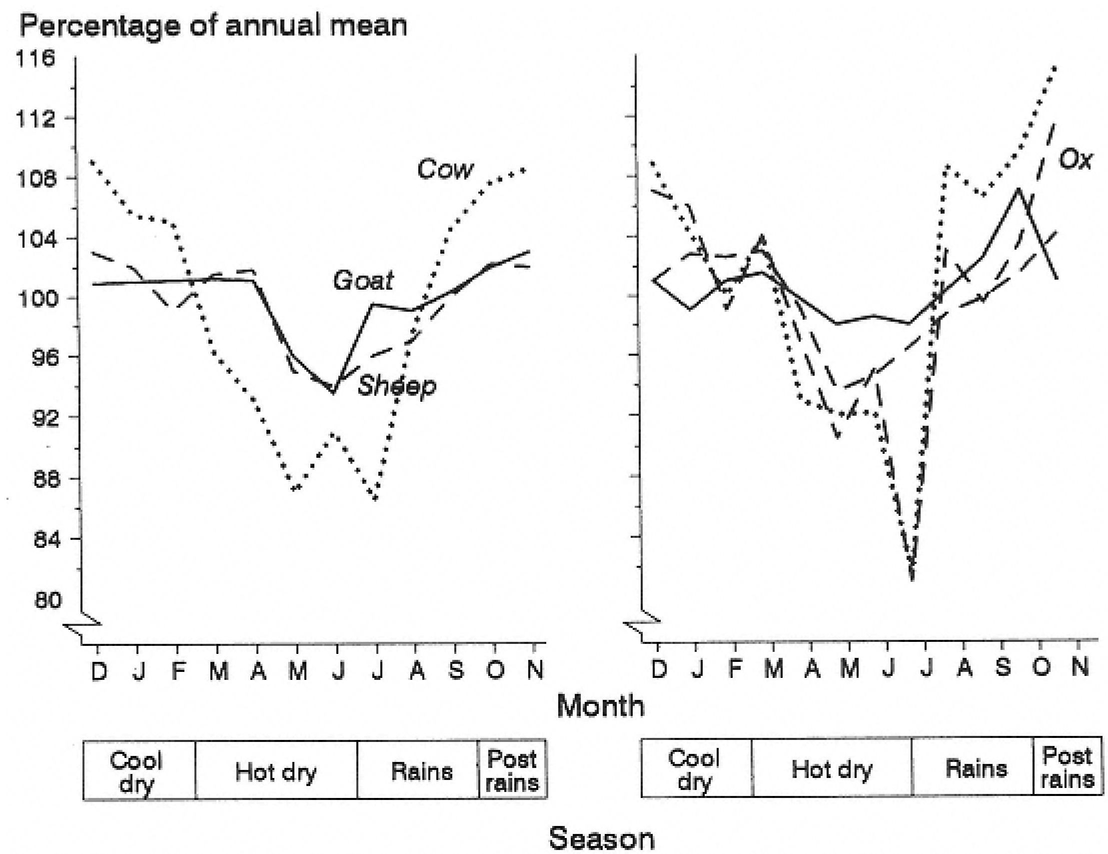


Fig. 10.6
Seasonal variations in weight of domestic ruminants in two agropastoral subsystems in central Mali; left, millet; right, rice.
(Source: Wilson, 1986.)

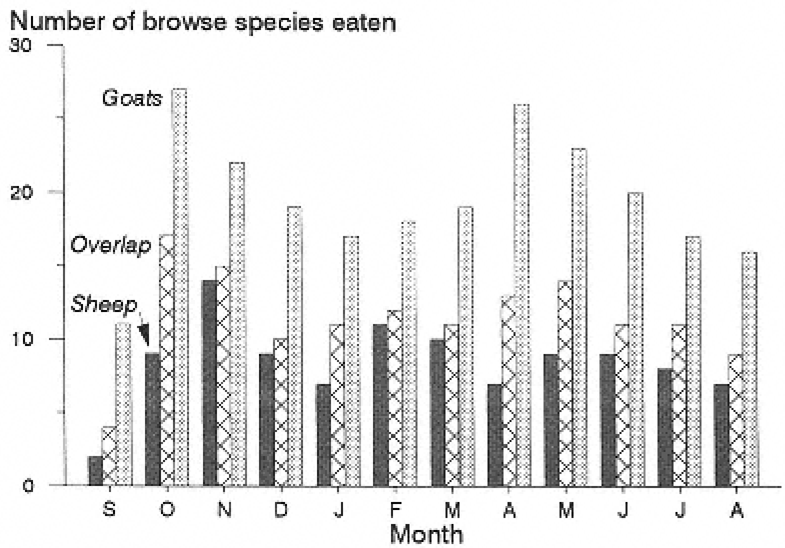


Fig. 10.7
Dietary range of goats and sheep and relative overlap on a thorn-bush savanna in Kenya.
(Source: Schwartz, 1983.)

dicotyledonous plants, mainly woody shrubs and trees. The aptitude of the goat to survive and reproduce on these plants means that it is often the last species to be seen in an area of general degradation. This should not be taken to mean that it is the cause of such degradation which may well have been caused by the generalist species that have destroyed their own feed resources and been taken elsewhere.

Feed selection can be viewed as both a tactical (short-term) and a strategic (long-term) problem and palatability is as important to the goat as to all other species. In this respect prior dietary experience of an individual is important in the feed it selects. At the species level, however, goats appear to be less deterred by, and have adapted better than other domestic animals to, some of the chemical defences against herbivory that plants have developed during their period of co-evolution with animals. Plants high in tannins and other antinutritional compounds are thus eaten more by goats, the process probably being aided by greater salivary secretion and the ability to recycle urea.

Feeding Behaviour

Goats select plant parts with high nutritive value in preference to coarser and lower value feeds. The narrow mobile muzzle and searching and prehensile tongue of goats enable them to pick green leaves of high protein content even when this type of resource is scarce. An adaptation to this type of behaviour, to which reference has already been made, is the ability of goats to assume a bipedal stance, so that they spend much of their feeding time at heights above the ground of 1.01.5 metres. In extreme cases goats have the ability to climb on to trees and shrubs in search of their preferred feed. Goats usually spend little time at a single feeding station and move rapidly from one to another.

Goats are active foragers. Feeding activity is, however, reduced in excessively wet conditions probably in part due to the effects of biting insects and the little protection that the animal has from these pests due to the nature of its coat. Cold also adversely affects foraging activity. In contrast they forage widely in hot arid conditions and continue to graze even after long periods of water deprivation. They compensate for limited feed of poor quality by extending their feeding area.

Opportunism in dietary habits is a major advantage in environments of fluctuating and often deficient nutrient supply. Goats are opportunistic to a high degree. Seasonal dietary shifts are sometimes very rapid as indeed they must be to

accommodate equally abrupt changes in feed availability. In northern Kenya flowers and fruits of *Acacia* spp. contribute as much as 40 and 20% of goat diets during their short period of dry season availability. In southern Tunisia a diet comprising 74% ephemerals and annuals in winter (this is a winter rainfall area) changed over a 4-week period to one with only 4% annuals. This was largely conditioned by the rapid desiccation and disappearance of annuals and a change to feeding on perennial shrubs such as *Rhanterium suaveoleus* and *Artemesia campestris*. Similar changes are recorded in Afghanistan where the shrub *Artemesia herba-alba* becomes an important dry season component of the diet. In India goats show different feeding patterns in the morning when they eat more than 80% grasses than in the evening when 69% of their intake was from shrubs (Solanki, 1994). In northern Mexico the consumption of herbs ranged from 0 to 14% of the diet in all months except April when this component jumped to 37% of intake, with *Sphaeralcea angustifolia* alone contributing 23% to total consumption.

Intake

Dry matter intake (DMI) is a function of age and productivity. DMI is an important initial consideration in nutrition since it reflects the capacity to utilize feed. DMIs for relatively unproductive goats at maintenance are probably about 1.41.7% of liveweight. Growing goats at different stages require 1.83.8% of liveweight. Meat goats have a DMI in the range 1.8 to 3.8% of liveweight whereas lactating and pregnant animals have higher requirements that may be in the region of 45% of body weight. Specialized dairy goats producing large quantities of milk have very high dry matter intakes equivalent to as much as 6.8% of liveweight or 180 g/kg0.75 which may only be achieved if a proportion of the diet is in the form of concentrates.

In South Africa DMI has been shown to be a function of bite size (the amount of feed taken at one bite) and bite frequency (the rapidity with which bites are taken). In one experiment Boer goats were able to achieve much higher intake rates than bushbuck (*Tragelaphus scriptus*) because they had greater bite sizes and a more rapid bite frequency (Haschick & Kerley, 1997). Intake rate is, however, a trade-off between the competing activities of cropping the feed and then chewing it so that there is a negative relationship between bite size and bite frequency. Plants with larger leaves thus lead to slower bite rates because of larger bite sizes.

Energy and Protein Needs.

Energy requirements for maintenance are about the same as for sheep and are 5.44 MJ/kg liveweight for a goat weighing 30 kg. Additional energy is needed for production. In arid rangelands, for example, 75% additional energy is needed to cover the increased walking requirements and muscular activity of the search for feed. Energy requirements for breeding females fluctuate in relation to stage of the reproductive cycle. They are highest when suckling young and lowest in the early stages of gestation. An additional energy input of 5.94 MJ is required during late pregnancy. There are further additional energy needs for milk and fibre production. Growth also requires energy and other nutrients to sustain it. Breeding rams and bucks generally have the lowest requirements for energy while fattening males have a level intermediate to that of females in the lactating and gestation phases (Fig. 10.8).

Protein needs for breeding females fluctuate in a way similar to those of energy. Breeding males usually need less protein but there is increased demand at mating. Protein needs for fattening are relatively lower, compared to energy, in relation to breeding females. In many parts of the tropics protein rather than energy is the main limiting nutritional factor. Protein deficiency can interfere with voluntary intake and delay growth and sexual maturity even if energy is adequate. An excess of protein can also affect reproduction. One aspect of protein utilization is the possible increased use of non-protein nitrogen

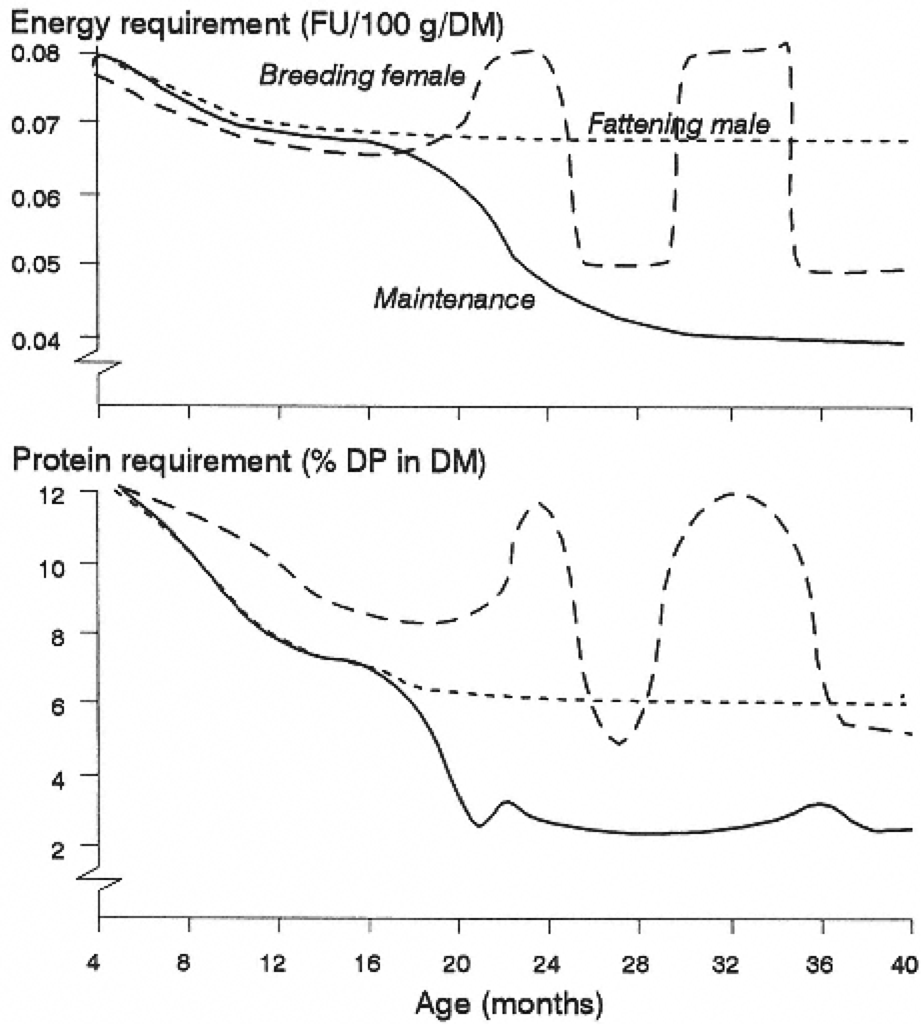


Fig. 10.8
Energy and protein requirements of male and female goats at various stages of the life cycle. (FU = forage unit; DM = dry matter; DP = digestible protein.)

(NPN) sources such as urea, biuret or poultry litter. Use of NPN not only reduces the cost of protein but ensures that a dietary supply is readily available. In Nigeria, for example, goats fed groundnut cake needed 53% more protein than those fed urea for every unit of gain which suggests that NPN may be used more efficiently than protein forms of the element. It must be stressed that effective use of NPN necessitates an adequate supply of soluble carbohydrates to ensure efficient microbial synthesis.

Minerals and Vitamins

Mineral and vitamin deficiencies, excesses or imbalances exert a considerable influence on goat productivity. Adequate phosphorus is critical for normal reproductive functions but deficiencies are likely under extensive range grazing. Calcium is also essential for normal body functions and the ratio of calcium to phosphorus should be about 1.2:1.0 under normal circumstances. Manganese deficiencies may affect calcium utilization whereas deficiencies in sodium, chloride and potassium reduce feed intake, contribute to heat stress and to poor hair formation. Zinc and manganese affect spermatogenesis, libido, oogenesis and the sex ratio of the young born.

Vitamin A and carotene are important in spermatogenesis and can best be supplied in green feed. If vitamin D is deficient utilization of calcium and phosphorus may be affected resulting in unthriftiness. Vitamin E has a beneficial role in reproduction and in preventing offflavours in milk. The B complex of vitamins are synthesized by the rumen microbes and do not normally pose any problems.

Digestibility

When provided with good quality feed there appears to be little difference in digestibility of most feedstuffs between goats and other domestic animals. Increases in apparent digestibility coefficients by goats, when given more than adequate quantities of feed, are due largely to the species' ability to select from the total on offer. If total feed availability is restricted then digestibility suffers.

Real differences in digestibility do occur, however, in feeds low in nitrogen and high in cell wall contents. These differences are due to the longer mean retention time of particles by goats, higher rumen concentrations of cellulolytic bacteria and a better balance of the total rumen microbial population, and to higher efficiencies in urea recycling.

Feed Sources and Supplementary Feeding

A variety of feeds is used for goats in the tropics. Common pasture and forage grasses include Guinea (*Panicum maximum*), Napier (*Pennisetum purpureum*), pangola (*Digitaria decumbens*) and setaria (*Setaria spendida*). In the drier tropics grasses include buffel or African foxtail (*Cenchrus ciliaris*), Rhodes or Columbus (*Chloris guyana*) and *Panicum coloratum*. Many trees, too numerous to mention individually are also used to provide nutrient requirements for maintenance and production; a review of these is provided by Devendra (1983).

Other major sources of feed for goats include crop residues and agro-industrial by-products. These include cereal straws and stovers, secondary output from oil milling including cotton seed and groundnut cake, and soya bean meal. Many crop residues are characterized by high lignin contents, low digestibility and low protein although their nutritive value can be improved by various forms of chemical, biological or mechanical treatment (Riquelme-Villagrán, 1988). Many agro-industrial by-products, on the other hand, are high in protein and are very useful feed supplements. Many 'non-conventional' feed resourcesthe term means those that have not been used traditionallyare also now being used in the face of feed shortages over much of the tropics (Devendra, 1985).

Strategies to ensure adequate year-round nutrition include wider and more intensive use of crop residues and expanded forage production on fallow land or as intercrops, and strategic use of energy and protein-dense concentrates. Leguminous forages fed green or as hay and ureamolasses or multi-nutrient blocks fed in small quantities do much to improve diet quality and hence productivity. Concentrate rations for goats (some examples of which are given in Table 10.7)as for other speciesshould be used with discretion and only when absolutely necessary. The cost of feeding should obviously always be less than the financial benefits of the product resulting from its use.

Where minerals are inadequate a supplement may have to be fed. This should contain common salt and trace minerals such as zinc, manganese, iodine, cobalt, iron, copper, molybdenum and sulphur. Kids, unlike lambs, are born with very low stores of iron and may need some supplementation.

Water is as essential to goats as to other livestock but actual needs are affected by such environmental factors as total DMI, the nature of the feed, ambient and drinking water temperatures and frequency of drinking. Physiological and genetic factors also affect water needs and intake.

Table 10.7 Examples of some concentrate mixtures suitable for feeding tropical goats.

Feed	Country, production objective and percentage of feed in mixed ration							
	Ethiopia (meat)	India (meat)	Malaysia (meat)	Mexico (meat)	Nigeria (meat)	Peru (meat)	Texas (mohair)	West Indies (meat)
Brewer's grains								33.0
Cassava chips			40.0					
Cassava flour					79.3			
Citrus meal								33.0
Coconut meal			37.1					
Cotton seed meal	20.0			30.0			60.0	
Dicalcium phosphate	1.0			1.0		1.0	2.0	
Fish meal				5.0				
Gram		15.0						
Groundnut meal		25.0						
Maize						25.0		
Maize cobs	40.0					31.0		
Maize meal	25.0	37.0		42.0				
Mineral mixture		2.5	1.5	2.0		1.0		1.0
Molasses	13.5		20.0		15.2	15.0		10.0
Poultry litter						25.5		
Salt	0.5	0.5	0.5			1.5		
Sorghum grain				20.0			38.0	
Urea			0.9		5.5			
Wheat bran		20.0						

Health

Diseases of whatever aetiological origin reduce animal productivity in all agroecological zones. The most important causes of economic loss related to health probably result from the parasitic and viral infections that are sometimes vector transmitted and whose prevalence is influenced by the environment. In monsoon areas the predisposing factors of heavy rainfall, high humidity and high temperatures are ideal for the onset and spread of disease and conditions are also favourable for insect and other vectors that are often primary or secondary hosts of disease organisms. Drier climates are often subject to less of these problems.

Apparent resistance to helminths in goats may well be related to their feeding habits and susceptibility increases if goats are forced to graze. Susceptibility to foot-and-mouth disease appears to be less, however, than for cattle and sheep. Trypanotolerance in West African breeds of goats appears to be stronger than it is in sheep. Major disease problems of goats include peste des petits ruminants (PPR), contagious caprine pleuropneumonia (CCPP), caseous lymphadenitis and caprine arthritic encephalitis (CAE). *Brucella melitensis* in goats is a cause of abortion and the presence of the bacteria in milk causes Malta fever or undulant fever in man if the milk is drunk.

Some diseases can be eliminated or their effects greatly reduced by vaccination. In West Africa, for example, it has been shown that a single vaccination against PPR, coupled with external parasite treatment to control mange mites (Fig. 10.9) substantially reduces mortality and morbidity (Sumberg & Mack, 1985). Preventive health measures are unlikely to be successful in the near future with goats because of the operational costs involved in organizing campaigns for what are mainly small production units and the low individual value of an animal.

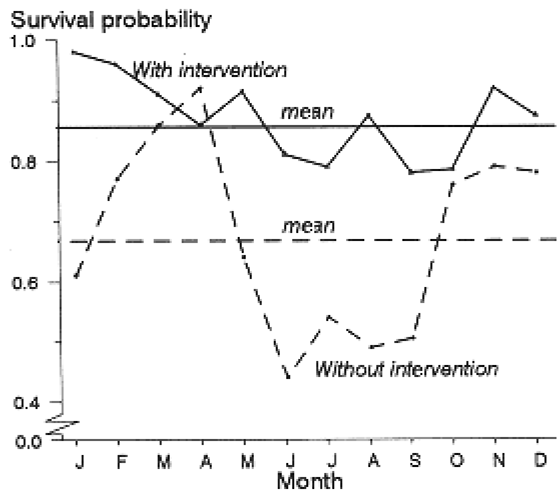


Fig. 10.9
Effects of vaccination against peste des petits ruminants and a treatment against external parasites on survival of West African Dwarf goats.
(Source: Sumberg & Mack, 1985.)

Major Diseases and Parasites

Infectious Diseases

Pneumonia is easily the most important bacterial health problem limiting goat production and is responsible for 631% of all morbidity. The major predisposing causes are the weather and bad housing. Microorganisms often associated with pneumonia include *Mycoplasma mycoides, Pasteurella multocida, Streptococcus* spp., *Staphylococcus aureus* and *Corynebacterium pyogenes*. Contagious caprine pleuropneumonia (CCPP) is a widespread bacterial disease. A similar disease occurs less frequently in sheep and is less severe. Pasteurellosis or haemorrhagic septicaemia, as in sheep, is also common in goats in the tropics. Stress, such as changes in weather, overcrowding and movement (hence another name 'shipping fever' for the disease) induce the onset of the disease which occurs mainly at the end of the rains and during the monsoon period. Rapid passage of the microorganism from one animal to another appears to increase its virulence so that healthy animals not under stress but in contact may become infected. Pneumonias are also caused or aggravated by lungworms, usually of the genus *Dictyocaulus*. The most common viral disease of goats is peste des petits ruminants (PPR) which may occasion mortalities of 50% or more. Although its control is not particularly difficult (see Fig. 10.9) the disease is being reported from more and more tropical areas.

Parasitic Infestations

Haemonchus contortus is the main helminth involved in gastroenteritis in most agroecological zones except the cool highlands. It causes high mortality particularly among young animals in the wet season. Other common species include *Ostertagia, Trichostrongylus* and *Oesophagostomum*. Coccidial oocytes are common in the faeces of grazing animals but clinical cases are overshadowed by the problems occasioned by helminth parasites.

Mange, caused by several species of mite including those in the genera *Sarcoptes, Chorioptes* and *Psoroptes* is common and widespread in goats. Its incidence may be as high as 80% even in free-ranging animals. Regular dipping or washing may reduce this to under 5% (Smith *et al*., 1988). Some new pour-on and slow-release chemicals are equally effective in goats as they are in sheep for the control of mites and other external parasites including ticks, fleas, lice and nasal bot flies.

Vector-Borne Diseases

Many vector-borne disease organisms have been identified in goats. These include *Babesia motasi, Anaplasma ovis*, *A. marginale*, *Trypanosoma vivax* and *T. congolense*. There is, however, no definite association between serological demonstration of these infections and clinical disease.

Nutritional and Metabolic Disorders.

Mineral imbalances are often responsible for low performance and fertility problems in domestic ruminants in the tropical zones. Animals fed on pastures deficient in phosphorus, cobalt or copper may be more affected by the absence of these elements than by energy and protein deficiencies. Research in tropical areas has shown that mineral supplementation can result in increases in birth rates of 20100% and in growth rates of 1025% and both of these may be coupled with a significantly reduced mortality. In some regions toxic concentrations of copper, iron, molybdenum or selenium may limit the production of ruminants. The outward manifestations of mineral imbalances vary considerably. They range from extreme cases manifesting a wide range of irrefutable clinical symptoms (Table 10.8) to occasional reductions in performance which are difficult to diagnose (Underwood, 1981). The latter is no doubt the most important as it affects a considerable number of animals over large areas and may be mistaken for an energy or protein deficiency or a parasitic infestation.

Nutritional disorders usually have less spectacular and deadly effects than the major epizootics but they nevertheless represent a considerable loss of income and greatly affect the economy of stock owners, especially in small-scale traditional systems. Research, especially on mineral deficiencies, should be intensified.

Effects of Disease on Inputs and Outputs

The effect of diseases on input use are mainly related to the costs for treatment or prophylaxis. The cost of application and veterinary care must be added to the cost of the drugs used for treatment. The cost escalates substantially when treatment has to be repeated or performed regularly, as for tick or tsestse control, or when animals need to be gathered from long distances for treatment.

Effects of disease on output may be direct or indirect. Direct losses include those due to mortality and morbidity. Losses due to livestock mortality in sub-Saharan Africa are estimated to cost US$2 billion per year. Losses attributed to morbidity as reflected by slower growth, reduced lactation yields and inefficient reproductive performance judged by parturition interval, birth rate, delayed puberty, and other factors are probably of the same magnitude. This is best reflected by offtake rates for meat, the main purpose for which small ruminants are generally raised, which remain at a low level of about 30%

Table 10.8 Some symptoms of trace element imbalances in small ruminants.

Symptom	Element and animal age group											
	Cobalt		Copper		Iodine		Iron	Manganese		Selenium	Zinc	
	Adult	Young	Adult	Young	Adult	Young	Young	Adult	Young	Young	Adult	Young
Anaemia	+	+	+	+			+					
Deformed hoofs											+	+
Dermatitis											++	++
Diarrhoea	+	+	+									
General debility	++	++	+	+							+	+
Goitre					++	++						
Hair slip						+					++	++
Heart problems			++	++						+		
Lameness			+	+				+	+	+	+	+
Loss of appetite	+	+	+	+	+	+	+				+	+
Lowered milk output	+		+		+						+	
Low fertility	+		+		+			+			+	
Muscular dystrophy												++
Pica	+	+	+	+								
Rapid breathing			+	+						+		
Skin discoloration			++	++								
Slow growth or fattening	+	+	+	+		+	+	+	+		+	+
Spontaneous fractures			+	+								
Staggering gait			+	+				++	++		+	+
Stiff hair	++	++	+	+		+					+	+

in much of the tropics. Mean carcase weight is also low at about 1213 kg per head. Another important effect of disease on production is changes in the value of the animal due to defects in conformation or rendering the products unfit for human consumption. Substantial revenue is also lost due to the failure of many producers to meet the health and sanitary requirements of lucrative export markets.

Among the indirect effects of disease is the inability of farmers or producers to use favourable grazing lands or resources, adopt new systems of animal management, introduce more productive genotypes or make full use of other animal products because the presence of disease increases the fear for subsequent morbidity or mortality. Diseases may also indirectly affect production through restrictions imposed on animal products as a result of treatment or vaccination and the implementation of control regulations following the outbreak of some diseases. The latter may range from enforced restrictions on animal movement to slaughter of sick and in-contact animals. Where animals are restricted in their movement it is not uncommon for overgrazing to follow as a further complication.

Management

Goats and sheep are often managed together in low input smallholder and extensive pastoral systems. Under free-ranging conditions goats are often the leaders in mixed flocks because of their rapid movement in search of feed and their inquisitive nature. Goats in smallholder systems are often tethered along road sides or other places where small quantities of feed are available. Household waste is often also fed to goats and this may be instrumental in encouraging them to return to the home each evening.

In smallholder systems it is not uncommon for goats to be kept in the owner's house at night or in rudimentary shelters. These are not always the most suitable type of housing as they may be crowded and unsanitary and open the way for disease infection. Suitable housing can lead to increased output and productivity. Housing for goats, as for other animals, must be spacious and airy with good circulation of air but free from excessive drafts. This does not mean that buildings need to be made of expensive materials as local timber and even crop residues are suitable items for use in goat houses. Houses raised on stilts with slatted floors (perhaps of bamboo or other similar material) are very appropriate for smallholder goat keepers.

Goats seem to have difficulty in adapting to very intensive enclosed management systems especially if this involves their being kept in large numbers and all their feed being cut and carried to them. This renders them susceptible to infection, especially to diseases of the respiratory complex and, if care is not taken, by helminths and mange. Goats are usually primarily browsers but they will produce large amounts of milk when intensively managed on a mainly grass diet. One experiment in the French West Indies with goats on pangola grass and fed a supplement, allowed a stocking rate of 126 goats and a production of 21 200 kg of milk per hectare.

Goats are increasingly being used, especially in Southeast Asia and West Africa, in systems with tree crops. The advantages of these systems are:

- Improved soil fertility due to the return of dung and urine
- Control of waste herbage
- Reduced use of herbicides
- Reduced use of fertilizers
- Easier management of the main crop
- Higher overall income and reduced risk from combined crop and livestock production.

Young Stock Management

Mortality in kids is highest at and close to birth. As much care and attention as possible should thus be provided at this time if excessive losses are to be avoided. Mortality at this stage is due to many causes. The most common causes include kids being weak at birth, malpresentation of the fetus, dams having poor or malformed udders, dams having milk fever, dams dying and accidents to dams and kids. Weaning can be encouraged by the provision of creep feed in the more intensive systems but is usually left to occur naturally in extensive systems. Castration of kids not to be kept for breeding can be done by the methods already described for sheep in Chapter 9.

Dentition and Age

As for other species, goats can be aged by means of their teeth. The dentition patterns of goats are very similar to those of sheep. As already indicated in Chapter 9, however, it is likely that eruption of the analogous series of teeth in goats is somewhat earlier than it is in sheep.

Production and Productivity

The major contributions of goats to human welfare are meat, milk and skins (Table 10.9). Fibre, mainly as mohair and cashmere, is an important secondary product.

Individual Weight and Growth

The considerations discussed under this heading for sheep in Chapter 9 apply also to goats. Weight gains of individual animals are of a similar order of magnitude for goats as for sheep of similar mature weights. The main sources of variation in weight gainbreed, sex, type of birth, age or parity of dam and season and year of birthare also similar for goats as they are for sheep.

Some goat breeds show exceptional growth characteristics with perhaps the most outstanding of these being the Boer goat of South African origin. Advantage can be taken of the growth characteristics of some breeds and the hybrid vigour that is conferred on their offspring to increase growth rates. In some crossbreds the dimorphism that exists between the sexes (Fig. 10.10) can be capitalized on to increase growth rates and meat production (Wilson & Murayi, 1988).

Meat

World production of goat meat increased by almost 80% from 1980 to 1994 (FAO, 1995). Production in centrally planned and developed countries remained static or declined but that of developing countries increased. The major proportional increase was in Asia (44%), followed by Africa (16%) and then South America (11%). In 1989 the developing countries produced more than 95% of the world's goat meat (Wilson, 1991a). Asia produces about 65% of world goat meat, Africa about 27% and South America about 3%. Meat from African goats is estimated at 43% of small ruminant meat production on the continent and small ruminants together contribute about 18% of all meat eaten there. As almost all small ruminant meat is from indigenous production and much of the beef is imported, it has been estimated (Wilson, 1984) that small ruminants contribute about 30% to indigenous meat production in Africa while being equivalent to about 17% of the standing domestic herbivore biomass.

Table 10.9 World production of goat meat, milk and skins (000 t) in 1994. (*Source*: FAO, 1995.)

Region	Total goats (million)	Meat	Milk	Fresh skins
Asia	373.0	2135	6135	460.2
Africa	176.1	662	2003	114.6
South America	22.8	74	182	13.7
North Central America	14.9	49	159	9.6
Europe	14.8	90	1633	17.1
Oceania	1.0	22		6.2
World	609.5	3057	10480	622.0

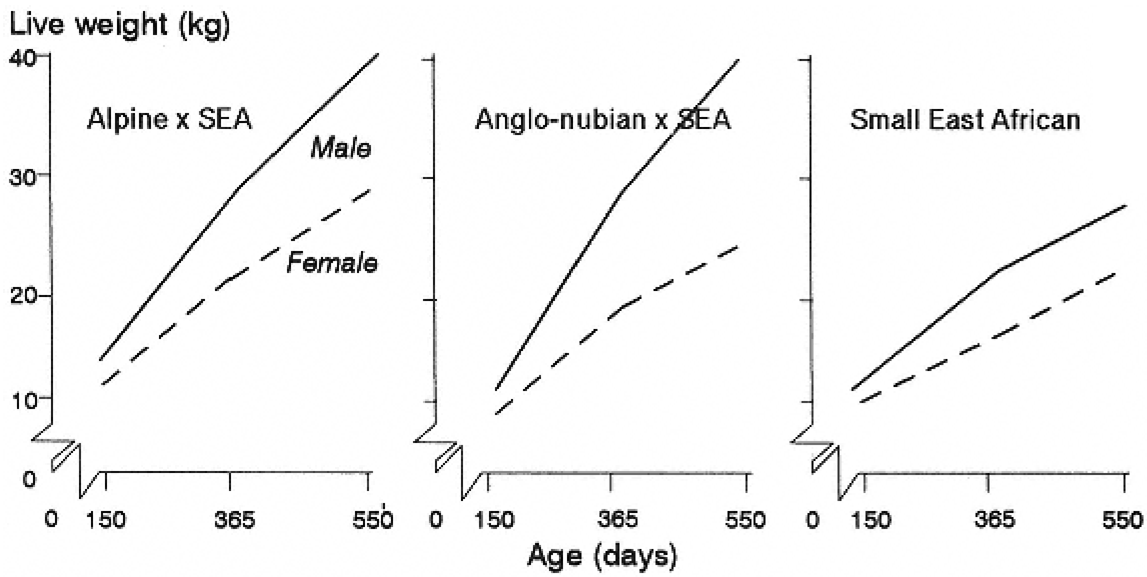


Fig. 10.10
Sexual dimorphism in growth rates in pure and crossbred goats in Rwanda.
(Source: Wilson & Murayi, 1988.)

Goat carcases average 12 kg in weight over most of the tropics but vary by country and by breed from 7 kg in Burkina Faso and Argentina to 18 kg in Swaziland and Peru. Offtake rates (number slaughtered as a percentage of total population) are estimated at 47% in Asia, 32% in Africa and 27% in South America. Goat meat available per person per year is 1004 g in Africa, 640 g in Asia, and 237 g in South America. Most goat meat is eaten in the area of production and meat from animals of all ages is consumed. In Latin America meat of very young goats, known as 'cabrito', of 68 kg liveweight is preferred. Flock structures throughout the tropics, which show overwhelming dominance of females in the age groups over 6 months, lead to a conclusion that most consumption is from young males aged 615 months. Meat of older goats, particularly males, is sometimes rejected because of the strong odour although the unpleasant smell can be avoided if early castration is practised. Goat carcases are leaner than those of sheep and have less fat cover as body fat is concentrated in non-carcase parts. In taste panel evaluations in the Philippines goat meat as hamburger and in a spaghetti mix had generally higher overall acceptability scores than beef or buffalo meat. Because of the lesser development of intramuscular fat in goat meat, it is more chewable than mutton. In West Africa the most important quality characteristic is the 'chewability' of the meat whereas in East Africa the degree of fatness in the carcase determines its value. The protein content of goat meat is 2022% with a fat content of less than 3%. The amino acids arginine, leucine and isoleucine are higher in goat than in sheep meat and goat meat is considered of adequate quality with respect to all essential amino acids. The biological value of goat meat is 60.4, compared to values of 68.6 and 59.5 for beef and buffalo.

Dressing percentage varies with many factors including, sex, breed, age, nutritional status and liveweight (Table 10.10). Total edible portions of the carcase are up to 7075% and the total that is commercially valuable can be as high as 80%. Females have less bone than males and yield more edible tissue at the same carcase weight but have less muscle because of a tendency to lay down more fat. Lean meat to bone ratios

Table 10.10 Dressing percentages and other carcase data of tropical goats.

Breed	Starvation period (hr)	Hot (H) or cold (C) carcase	Dressing %	Total edible %	Commercially valuable %	Source
Sudan Desert			46.0			El-Hag *et al*., 1985
Sudan Desert			36.3			Ibrahim & Gaili, 1982
Sudan Desert	12	H	48.251.2			Wilson, 1976
Long-legged Sahel	12	H	49.0			Wilson, 1984
East African (SEA)			43.5	48.3	55.5	Wilson, 1958
Rwanda-Burundi (SEA)			39.1			Thienpont & Vandervelden, 1961
Malawi (SEA)			50.2	73.5	80.5	Owen, 1975
Malawi (SEA)			44.046.8			Kamwanja *et al*., 1985
Botswana			43.3	71.8	79.2	Owen *et al*., 1977
Mauritius		H	40.4			Fielding, 1980
West African Dwarf	12	C	46.748.6			Adebowale & Ademosum, 1981
West African Dwarf	12	H	50.051.2			Akinsoyinu *et al*., 1975
WAD × Red Sokoto	20	H	46.1			Kareem, 1977
Boer, Kamori	24	C	45.4			Kyomo, 1978
Angora crosses			53.1			Ghanekar *et al*., 1973
Jamunapari (India)			55.8			Khan & Sahni, 1979
Katjang (Malaysia)			44.247.4	61.271.5	81.596.2	Devendra, 1966

increase as body weight increases and vary from as little as 2.7:1.0 in dairy goats to as much as 3.8:1.0 in Jamnapari and 4.9:1.0 in Barbari breeds.

In most tropical countries markets for goats are much less formal than they are for cattle and sheep. Most goats are, therefore, traded at the local level or slaughtered for home consumption. In both of these situations they are advantageous to man during periods of cyclical and unpredictable food shortages in their relative and absolute contributions to the supply of meat. It has been estimated (Wilson, 1991a) that the ratio of meat production to the percentage of the domestic herbivore liveweight biomass is 2.17 for goats, compared to 1.68, 0.91 and 0.41 for sheep, cattle and camels respectively.

Goats are also adapted to balancing the energy and protein supply available to people during normal variations occurring over the years as well as between different seasons. In Mali, for example, goats provide about half of the total quantity of meat sold to consumers living in the towns, the greater part of this being available towards the end of the dry season when there is little other red meat on the market (Fig. 10.11).

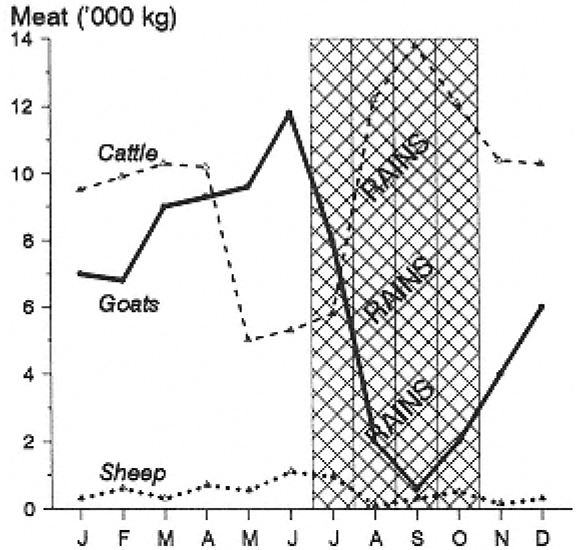


Fig. 10.11
The contribution of goats, sheep and cattle to the meat supply of a Malian town in 198182.
(Source: Wilson, 1991a.)

In Kenya, in a modified traditional system in which veterinary medicines were supplied, goats provided 18% of the minimum calorific requirements (in meat and milk combined) of the human population. They were surpassed by camels (27%) but contributed more than sheep (12%) and cattle (16%), with cereals and other sources (27%) making up the remainder of the diet. In this system of the Rendille tribe, goats provided 33% of the minimum protein requirements even though protein availability was in excess of that required. In other regions of Kenya, goats provide about 75% of the total meat consumption in pastoralist households (Schwartz, 1986).

Where goats are marketed through conventional channels their carcases are usually evaluated by the standards developed for sheep. Although dressing percentages are usually as high as or even higher than those achieved by sheep the distribution of goat fat in the peritoneum and on the viscera (cf Table 10.3) leads to a different visual impression of 'quality'. Goats have therefore usually been classed in the lowest grade or even rejected as ungraded, leading to low prices and producer disillusionment.

Dressing percentage generally increases with liveweight. Females often dress out better than entire males and castrates. Month of slaughter influences body and carcase weights as well as dressing percentage. April body and carcase weights for Bornu White goats in Nigeria were 15.7 and 22.9% lower than in December. For the Red Sokoto these figures were 18.3 and 25.3% (Alaku & Moruppa, 1983). A comparison of carcase characteristics between breeds provides information on their performance levels under defined management and environmental conditions. In a study of Bornu White and Red Sokoto goats during the West African Sahelian late dry season declines in both body and carcase weights were greater in the Red Sokoto than in the Bornu White (Fig. 10.12). The differences in weight loss between the breeds were considered to be due to morphological differences. The Bornu White, with long legs, white colour and long pendulous ears seems to be better adapted to high temperatures than the smaller Red Sokoto with brown colour, shorter legs and shorter ears (Alaku & Moruppa, 1983).

Milk

In several tropical countries there are restrictions or taboos on goat milk. Many people believe it is best used as a medicine and others that it causes disease or is used in witchcraft. Many of these taboos now appear to be ill-founded and may be associated with a supposedly low social status. Tested on a hedonic scale of 1 to 5 (1 = like very much, 5 = dislike very much) goats' milk scored higher than cows' milk in Kenya over four sample surveys with an average of 1.65 points against 1.43. The acceptability of goats'

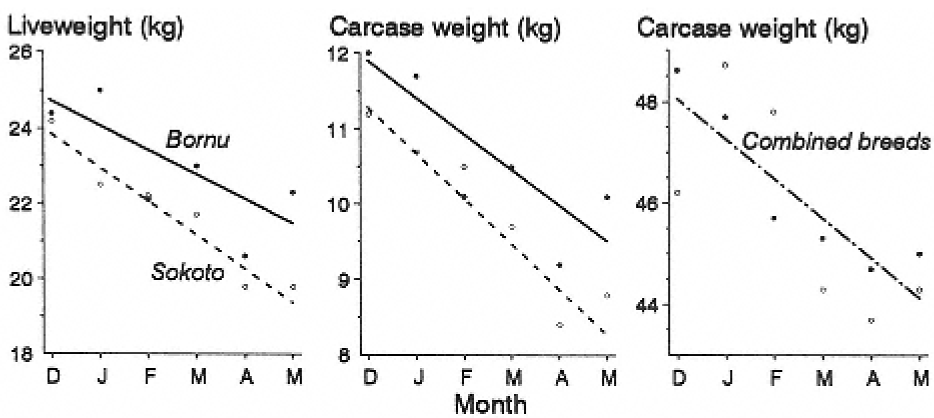


Fig. 10.12
Changes in live and carcase weights and in dressing percentage of two West African breeds of goats in Nigeria.
(Source: Alaku & Moruppa, 1983.)

milk should not therefore present any problems if negative attitudes to it can be overcome.

Some special attributes of goats' milk are:

• Although the range in size (110 µm diameter) of fat globules is the same as in cows' milk, there is a greater proportion of small globules in goats' milk (Fahmy *et al*., 1956) those of <4.5 µm being 82.7% of the total in goat compared to 85.7, 62.4 and 40.9 in sheep, cow and buffalo milks.

• Fat and protein are very easy to digest and goats' milk can be tolerated by people who are allergic to cows' milk.

• The vitamin A content is readily available in the absence of carotenoid pigments and precursors.

Goats' milk is widely consumed in the tropics where it is usually drunk fresh and adds a valuable animal protein element to the diets of many tropical and, especially, rural poor households. The small but consistent contribution of goat and sheep milk (cf Fig. 9.12) to vulnerable groups of the human population, including subsistence farmers in general, pregnant and nursing mothers and small children, often makes the difference between adequate and under nutrition. The biological efficiency of cows' and goats' milk production are probably about the same under modern management. The practical efficiency of production in much of the traditional small-scale farming and extensive pastoral areas of the tropics is, however, heavily weighted towards the goat.

Lactation Length.

By world standards, lengths of lactations of tropical indigenous goats are short and generally in the range of 80200 days, although some tropical breeds do have long lactations (Table 10.11). It should be noted, however, that milking for commercial purposes hardly exists, offtake for human consumption is usually on an opportunistic basis and may occur at any stage of lactation, and weaning of young is spontaneous rather than directed. Attempts to prolong lactation length usually involve crossing with exotic breeds, especially in Africa (Table 10.12), Crossing with exotics, depending on the level of blood introduced, usually prolongs lactations by as much as 50%. The genetic effects of breed appear to be the major ones affecting lactation length. Coefficients of variation of the order of 25% among individuals indicate that some improvement in lactation length would be possible. No environmental effects on lactation length have yet been identified.

Persistence

Persistence of lactation appears to be principally an effect of breed although there are genotype × environment interactions and individual effects. In Burundi, under station conditions, all purebred Alpine goats had lactations of at least 4.5 months and 55% were still milking at 7.5 months (Fig. 10.13). Half- and three-quarter-bred Alpines had greater persistence under station conditions than in the traditional environment.

Daily Yield

Daily yields vary in the range 0.252.00 kg per day (Tables 10.11 and 10.12). In addition to

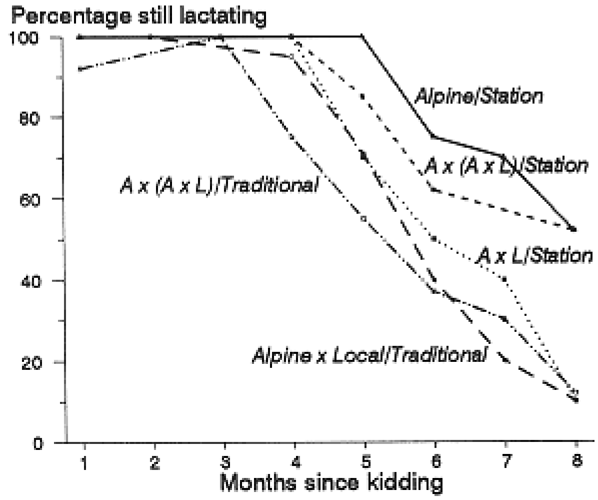


Fig. 10.13
Lactation persistence of goats of various genotypes
and under different management in Burundi.

Table 10.11 Milk production parameters of goats in South, Southeast and Western Asian tropics and subtropics. (*Source*: adapted from Devendra & Burns, 1983.)

Country	Breed type	Lactation details		
		Length (days)	Daily yield (kg)	Lactation yield (kg)
India	Barbaria	180252	1.6	150228
	Black Bengalb			2530
	Chigu	100110	0.4	40
	Ganjam	100	0.5	50
	Jhakrana	115	1.0	122
	Kashmiri	100	0.2	20
	Jamnapari	170200	1.53.5	200562
	Beetala	208	1.2	140228
	Gaddia	90100	0.8	4050
	Malabari	181210	1.0	100200
	Marwari	106	0.9	90
	Sirohi	134	0.9	116
Pakistan	Chappar	105	0.7	75
	Damani	105	1.0	104
	Dera Din Panah	130	1.5	200
	Kamori	120	1.8	228
Malaysia	Katjang	126	0.60.8	90
Israel	Black Bedouin		1.3	2.0
	Mamber		1.5	350450
Iran	Nadjdi	250	1.0	250
Cyprus	Damascus (Shami)	190290	2.00	500560
Turkey	Angora	123164	0.5	3568
	Kilis	260	1.0	280

a India/Pakistan.
b Bangladesh/India.

genotype effects a number of environmental variables have been identified, a major one being the size of the litter (Akinsoyinu *et al*., 1977). Total yields are as much as 50% higher for dams suckling twins than for those suckling singles as shown for both Boer and Red Sokoto goats in Africa (Fig. 10.14). Tropical small ruminants, as many tropical cattle, appear reluctant to let down milk in the absence of young. Boer goats in South Africa (Casey & van Niekerk, 1988) produce less than a third of the quantity when hand-milked (0.48 kg) than when suckled (1.55 kg). Less pronounced differences have been noted in Malawi on much lower overall yields; suckled does produced 0.29 kg per day compared to 0.21 kg for hand-milking and 0.23 kg for hand-milking following oxytocin injection (Phoya, 1982).

Lactation Yield

Total milk produced is a function of the duration of the lactation and the daily yield. In Africa lactation yields vary from as little as 24 to as much as 480 kg (Table 10.12). Factors which influence total yield are generally the same as those influencing daily yield. Age of dam has a strong influence although this is mainly through

Table 10.12 Milk production parameters of African goats and their crosses with temperate breeds.

Country	Breed type	Lactation details			Composition %				Source
		Length (d)	Daily yield (kg)	Lactation yield (kg)	Fat	Solids-not-fat	Protein	Lactose	
Burundi	Local[a]	108	0.31	34					Hanon, 1976
	Alpine × local[a]			216					Cyrille Ntahimpereye, pers. comm.
	Alpine × (Alpine × local)[a]	259		356					Cyrille Ntahimpereye, pers. comm.
	Alpine × (Alpine × local)[b]			215					Cyrille Ntahimpereye, pers. comm.
	Alpine	240		481					Cyrille Ntahimpereye, pers. comm.
Tanzania	Norwegian	207	1.09	217	3.3				Eik *et al*., 1985
	Local × Saanen	154	0.70	105	6.9				Eik *et al*., 1985
	Red Sokoto	105	0.47		4.6	11.1	4.7	5.2	Akinsoyinu *et al*., 1981
Nigeria	Red Sokoto		0.54			5.3		4.8	Ehoche & Buvanendran, 1983
	West African Dwarf	126	0.32		8.3	10.9	5.1	4.5	Akinsoyinu *et al*., 1977
Niger	Red Sokoto	200		150					Robinet, 1967
Malawi	Local	112	0.25		6.7	9.6	2.2	6.3	Phoya, 1982
South Africa	Boer	84	2.00	150					Casey & van Niekerk, 1988
	Boer[c]	120	1.27	160	5.6	10.1	3.0	6.1	Ueckermann *et al*., 1974
	Boer[d]	120	1.81	128					Ueckermann *et al*., 1974
Ethiopia	Adal	84		24	2.9	8.9	3.3	2.8	Kassahun Awgichew *et al*., 1989
	(Saanen × Adal) × Adal	84		31					Kassahun Awgichew *et al*., 1989

a On station.
b Traditional system.
c Suckling single kid.
d Suckling twin kids.

daily yield as lactation length does not differespecially in Ethiopia where females aged 7 years produced 50% more milk than those aged 2 years.

Milk Composition

The nutritive value of goats' milk is of special interest (Jenness, 1980; Chapter 18 in this book).

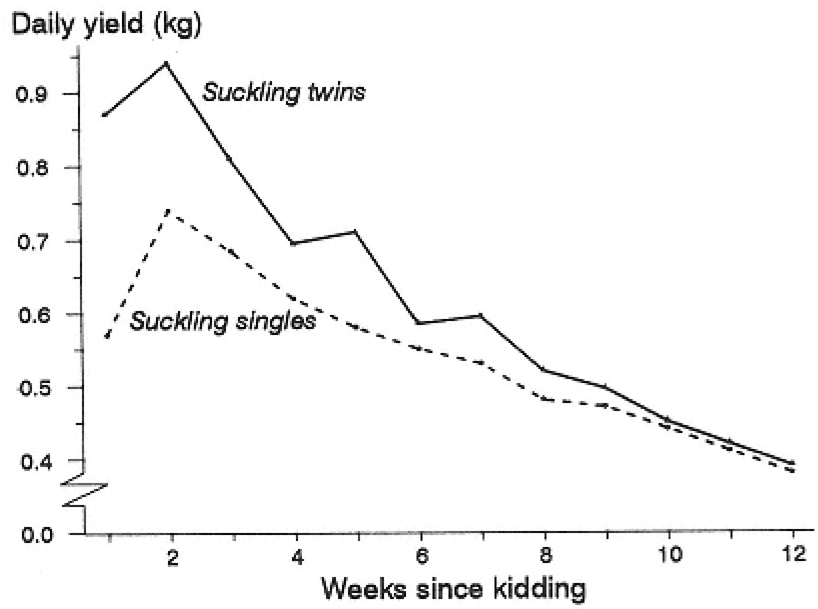


Fig. 10.14
Lactation curves of Red Sokoto goats in Nigeria when suckling twin and single kids.
(Source: Akinsoyinu *et al*., 1977.)

Goat, cow and human milks contain approximately the same amount of energy at about 3.10 MJ/litre but there are differences in the proportion derived from lactose and protein. The supply of protein, calcium, phosphorus, vitamin A, thiamin, riboflavin and pantothenate is in excess in goats' milk but iron and vitamins B12 and C are deficient. Goats' milk has a satisfactory balance of amino acids that equal or exceed the standard recommendations for human nutritional needs.

Data for the tropics show rather high fat contents in goats' milk (Table 10.12). Breed effects on the percentage of milk fat are very noticeable, ranging from as little as 2.9% in the Adal to 8.3% in mid-lactation in the West African Dwarf. Fat content is usually highest in early lactation but there is some variation and fat may increase again towards the end of lactation. Lactose and protein usually increase with advancing lactation but total solids diminish. In Red Sokoto goats age had no effect on fat or protein content (Akinsoyinu *et al*., 1981) but does suckling twins (5.03%) had significantly higher milk fat content than those suckling singles (4.37%). The indications are that fat percentage decreases with increasing yield, as does protein, but there is a strong positive correlation between fat and protein contents.

In Red Sokoto goats in Nigeria values for total solids (14%), protein (8%), fat (43%) and energy (20%) were all higher in colostrum than in milk but lactose was lower (8%). Overall composition approached that of milk by 6 days after parturition.

Breeding for Milk Production

Major constraints to increased milk output, in addition to initial consumer resistance, are lack of management skills, inadequate feed supply and inappropriate and ill-adapted genotypes. Inappropriate genotypes may be purebred imported exotics or crossbreds of exotics with locals. Ill-adapted genotypes may be ones that do not survive in the tropical management, nutritional and health environment or are not acceptable to producers. Both situations may arise due to inadequate knowledge of performance, or of potential performance, under the existing social and biological conditions.

Interesting experiments and field trials, and modelling based on these, have been carried out with reference to a Kenyan traditional mixed

farming system (Ruvuna *et al*., 1987). Experiments used two local breeds (Small East African and Galla) and two established milk-producing breeds (Toggenberg and Anglo-Nubian). Simple two-way crossbreds produced more milk than local unimproved goats but required constant renewal and management skills superior to those generally available in Africa, as well as higher levels of nutrition. Composite or synthetic breeds lose less heterosis due to recombination during stabilization than simpler crossbreeds and are more responsive to selection for maintaining or increasing production. Animals can then be bred for a fixed body size and/or maximum milk yield. The model showed it to be possible to produce a goat of 50 kg mature weight capable of yielding 5 kg of milk per day. This genotype, however, was not able to produce to its full potential under the management and other environmental conditions that could be provided. Of two other genotypes tested one, bred for 40 kg weight and 3 kg milk, outperformed at the flock level another bred for the same weight but for 4 kg milk. This was because the former was able to adapt better to the protein and energy supplied from farm resources and purchased inputs. This example shows how 'improved' animals are not necessarily 'best' under all tropical conditions.

Skins and Fibres

Skins

Skins are an important but often neglected by-product of goat production and are produced by every animal. Fibres, in the case of goats, are limited to some specialized mohair and cashmere production and some common hair.

Most skins are absorbed by local or national economies but in some countries they contribute considerably to exports. In Botswana, for example, revenue to the Botswana Meat Commission from goat skins was equivalent to 20% of that obtained from meat; in Ethiopia in 1983 some 1.8 million goat skins and 3.3 million sheep skins earned revenue equivalent to 9.2% of all agricultural exports and equivalent to 29.5% of agricultural exports excluding coffee. Goat skins from sub-Saharan Africa are important in world trade and particularly in the quality markets. A move from exporting raw skins to at least some form of manufacturing is a practice that has developed rapidly in Africa (Wilson, 1992). The switch from raw exports to partial manufacture is exemplified by Ethiopia over the 10-year period 197887 (Fig. 10.15).

Goat skins are easily distinguishable from sheep skins by their tight, firm structure, and from cattle hides by thickness but also by the fact that cattle have fats both near the hair root and deep in the skin near the flesh. Goat skins also have less hair and less fat than sheep skins which have many fat glands and hair roots and an open structure. Coarse-haired goats produce a grain appearance different from that of a fine-haired goat. Although all grades of sound goat skin are usable there is a premium for fine-grained leather that has satisfactory physical properties.

Some breeds of goats are well known for producing quality skins. In Africa these include the Red Sokoto (whose skin is known as 'Morocco' in the leather trade) from Nigeria and Niger and the Mubende from Uganda. Skins from these goats usually weight 400500 g when air dry while skins from larger breeds usually weigh 500600 g. Average dry weight of all Red Sokoto skins from Nigeria and Niger is some 420 g, varying from 'extra light' at 250 g to 'heavy' at 625 g. The useful area for tanning is from 0.28 to 0.65 m2. The skins are characterized by deep and pronounced grain, dense and compact elastic fibres with little grease, and ease of tanning. They are in demand for the fancy goods trade, particularly for gloves, high quality shoes, patent leather and suede clothes.

Mohair

Mohair from Angora goats is a highly valued product in the textile industry and commands a higher price than sheep wool. Mohair in the tropics is almost entirely of Southern African origin with Lesotho as well as the Republic of South Africa being the main sources although very small amounts are produced by Kenya where

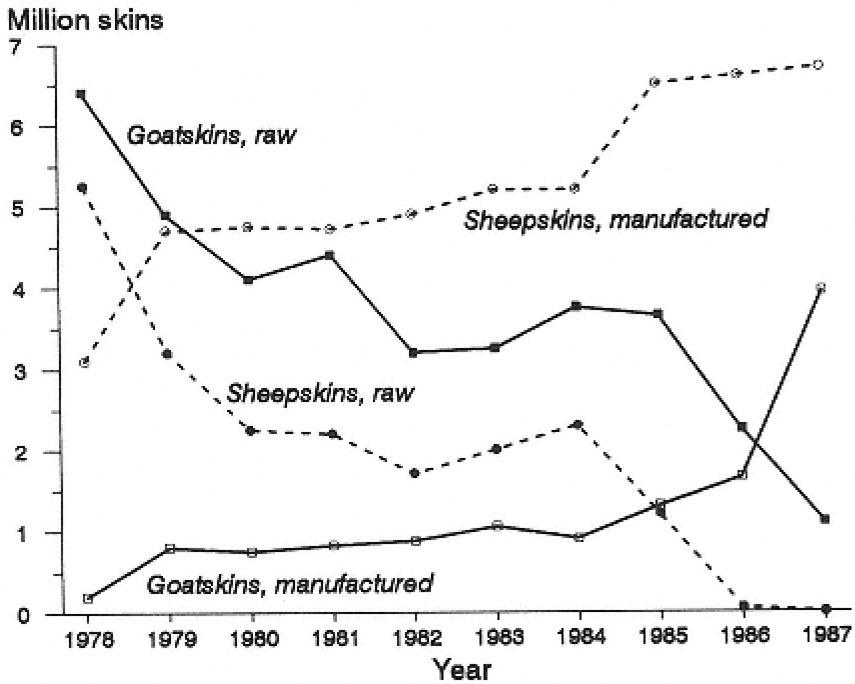


Fig. 10.15
Trends in export of manufactured and raw goat and sheep skins from Ethiopia.
(Source: Wilson, 1992.)

Angoras are of some importance under commercial conditions. Tropical mohair is mainly marketed through South African channels which in terms of both quantity and quality is the world's most important producer of this commodity. The criteria used to determine quality are the same as those for sheep wool: staple length, diameter, density, fibre distribution on the body of the animal and fibre colour. The diameter of mohair usually varies between 22.9 and 74.5 µm. As in the case of sheep, secondary fibres are of a superior quality, the ratio between these and primary fibres varying between 2.0 and 10.5.

There were an estimated 1.0 million mohair-type goats in Lesotho in 1986 compared to 618 000 in 1978 (Makhooane, 1987). Mohair production increased from 507 000 kg (0.82 kg per head) to 788 000 kg (0.80 kg per head) over the same period (Wilson, 1992), the values of exports being US$2.45 m and US$6.07 m in 1978 and 1986 respectively (Fig. 10.16). Bucks continue to be imported from South Africa (Fig. 10.17)275 were imported in 1986as Lesotho strives to build up its own stud.

Cashmere.

Cashmere is a major product of goats in China and is becoming of increasing interest elsewhere because of its high economic returns. The Chyangra goat of the Mustang district in Nepal is used for pack purposes but its main product is cashmere. The long outer coat has a staple length of 40200 mm and covers the fine inner coat with a staple length of 2590 mm. Annual cashmere yield is 115170 g per goat. Slate or blue grey is the most common colour but white and other colours occur (Wilson, 1997). The fine undercoat of Nepal's Sinhal goat is also sometimes combed out but the down is of poor quality compared to that of the Chyangra.

Constraints to Increased Productivity and Opportunities for Development

Goats are often closely integrated into smallholder systems especially in the humid, sub-

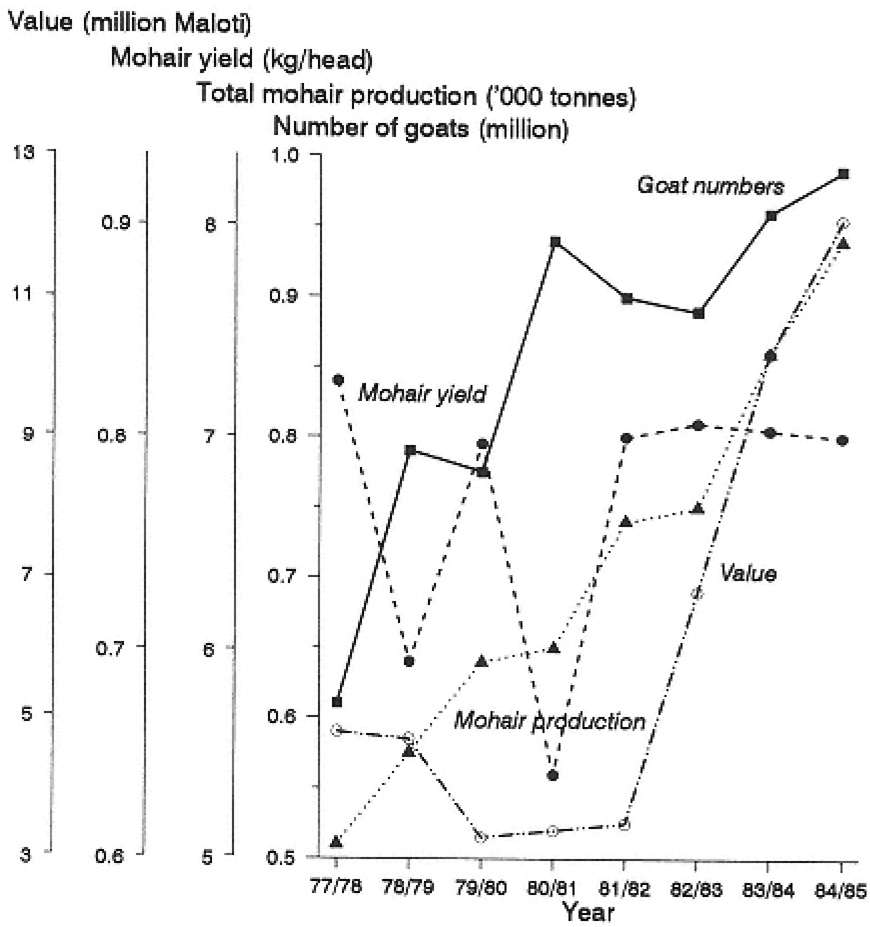


Fig. 10.16
Biological and economic parameters of Angora mohair production in Lesotho.
(Source: Wilson, 1992.)

Fig. 10.17
An Angora stud buck, originally imported from
South Africa, on a Lesotho government farm.

humid and semi-arid tropics. There is now considerable interest in their role and functions. In many areas, however, they continue to be ignored or misunderstood and may be considered to be 'uneconomic' because of their small size or as being destructive of the environment. Much research continues to be aimed at a single crop or product and largely ignores the contribution that the goat can and does increasingly make to food security and system sustainability.

High levels of morbidity and mortality are a major cause of low levels of productivity. Reducing the mortality rate would be equally as effective in raising output as would improving reproductive performance and increasing growth rates. Reducing mortality is not, however, a simple problem which can be achieved only by identifying and eliminating the pathological agents. An integrated approach involving health, nutrition, management and the manipulation of environmental and genetic factors is most effective. Integration at the system level is equally as desirable as at the level of the individual animal. Disease, through morbidity, mortality and poor reproduction largely manifested as reproductive wastage, significantly reduces flock productivity and may reduce the returns to rearing goats. Some measures which may minimize the impact of disease and reproductive wastage on productivity are:

• Identification of major causes of disease and poor reproductive performance

• Application of appropriate and well-designed prophylactic measures to control diseases and minimize reproductive wastage.

Skins and fibres from small ruminants can contribute considerably to diversifying the product base of national economies and to the quality of life of the animals' owners. Production of manure, increased use and nutritional modification of crop residues for better feed value, and integration of goats with tree crops offer possibilities for more rational and effective use of goats in mixed sustainable systems that will also lead to reduced production risk. More campaigns of public awareness should be made in order to ensure that goats can be allowed to play their full role in the economies of tropical countries.

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11
Old World Camels

Introduction

It is often considered that camels were primarily used in the past for transport of people and goods in deserts and semi-arid areas. Milk, meat, hair and hides were then subordinated to by-product status of the supposed primary function. It is true that the most obvious role of camels to the outside world was one of transport but it is almost certain that in camel production systems this was a secondary functionor at best had co-equal importance onlywith milk production for human subsistence. One-humped camels (Fig. 11.1) are multi-purpose animals where they are found over much of the arid and semi-arid tropics and the Bactrian camel (Fig. 11.1) has similar functions in the colder deserts of Asia. Females are used primarily as milk producers, males are used for transport or draught and both sexes provide meat as a tertiary product (Wilson, 1984). Accumulation of capital to provide long-term security is also an important function in most areas. 'Prestige' in the modern sense derives from owning successful racing stock.

Camels made a remarkable comeback towards the end of the twentieth century. Somewhat neglected until the start of the 1980s, there has been increased interest by scientists in their ability to survive and produce in harsh and hostile environments and by development workers in their role as life-support systems in these same environments. Camels are now better understood and being used in a wider range of roles than at any other time in their history. In spite of the minimal contribution of the camel to overall world animal production it has continuing importance as an essential element of the human life-support system over vast dry land areas. Its unusual or even unique physiological features and its complementarity of resource use with other domestic species and with wildlife (Schwartz & Schwartz, 1985; Wilson, 1986a) mean that it is able to occupy a large and otherwise virtually empty niche and contribute to sustainable systems of production in harsh and marginal environments.

Origins

Both Old World and New World camels are of the subfamily Camelinae of the family Camelidae in the suborder Tylopoda of the order Artiodactyla. 'Camels' are even-toed ungulates but differ from most others of their order in having soft, padded feet. Generally referred to as ruminants, or occasionally pseudo-ruminants, because of their ruminating habit, camels do not belong to the same suborder as the other major meat and milk producing domestic herbivores.

There is confusion over terminology at the generic level but it is now generally accepted that Old World camels are one genus, *Camelus*, and that New World camels are also one genus, *Lama*. Within *Camelus* it is customary to accept two species: *C. dromedarius*, the one-humped or Arabian camel or dromedary; and *C. bactrianus*, the two-humped Bactrian camel. The species division is not biologically correct as the two freely interbreed in either direction and produce fertile offspring.

Fig. 11.1
One-humped camels *Camelus dromedarius* in Botswana

A two-humped Bactrian camel *Camelus bactrianus* in Mongolia.

All camelids evolved in the western part of the North American continent (Fowler, 1997). The Tylopoda were recognizable in the Middle Eocene of 50 million years ago and were well differentiated in the Upper Eocene some 10 million years later. Early camels were small but during evolution some subfamilies comprised genera in which animals were very big, as indicated by their generic names such as *Megatylopus*, *Megacamelus*, *Gigantocamelus*, and *Titanotylopus*. Some species migrated across the land bridge from North America to Asia, eventually reaching Europe and Africa, whilst others migrated into South America. These migrations probably occurred during the Pliocene or early Pleistocene about 4 to 3 million years ago. Camels disappeared from North America at an unknown period.

The earliest true camels were probably closely related to the modern Bactrian camel that now occupies cold arid and semi-arid areas from the Kalmyk Republic in the Russian Federation to the north of the Caspian Sea eastward through the Central Asian Republics of the former Soviet Union and northern Afghanistan to China and Mongolia. There are still up to 1000 free-roaming Bactrian camels in some parts of the Republic of Mongolia and in adjoining northwestern China. These have long been thought to be feral, some authors now consider that they are truly wild (Tulgat & Schaller, 1992; Hare, 1997) and are descendants of the original stock that once ranged across Asia at least as far west as modern Kazakhstan.

The modern one-humped camel possibly evolved from the Bactrian as it possesses a vestigial anterior hump that is present in the embryo as well as in the adult animal (Nawito *et al*., 1965). It is likely that this evolution took place in one of the hotter and more arid areas of Western Asia, possibly central or southern Arabia. No feral or wild types of the one-humped camel are known although there is evidence that there were once wild animals in Western Asia and parts of Africa (Zeuner, 1963).

Domestication

The genus *Camelus* was probably among the last of the major domestic species to be put to regular use by man. References to the one-humped camel as a domestic animal in the early books of the Old Testament of the Christian Bible and in the Koran probably result from later 'editing'. There is little direct evidence for an exact time of domestication, principally because camels have changed relatively little as a result of selection and, whereas it is possible at archaeological sites to observe the changes in other species, this is not the case for camels. An additional reason for the lack of archaeological evidence is that early camel owners, as present ones, were nomadic and left few permanent mementoes of their presence. The most likely time of domestication, however, is probably about 4000 BP (before present), or slightly earlier.

Little is known of the centre of domestication of the Bactrian camel. Southern Arabia (in what is now the northeastern part of Yemen and the west of Oman) is the most likely area of domestication of *Camelus dromedarius*. After about 3700 BP there are more and more records of the use of one-humped camels in Western Asia. Camels were known in India by 2500 BP although they were probably not of any great importance there until the Baluchi people arrived about 1000-800 BP (Bulliet, 1975). Camels were probably unknown in Egypt until the Assyrian and Persian invasions of 2700-2600 BP and there are few records of their presence in Africa before Roman times. The present distribution of camels in Africa probably stabilized after 1200 BP with the spread of Islam.

One-humped camels were introduced into Western Europe by the Arabs although they were apparently present in Eastern Europe much earlier as a stone frieze of Roman times at Plovdiv in Bulgaria shows one in a mixed pack caravan with horses and donkeys. The one-humped camel was known in Spain in AD 1019 and in Sicily by 1058. There were many other minor attempts to import camels to Europe (Wilson, 1984). With the colonization of the Americas, Southern Africa and Australia by Europeans camels were introduced and occupied places of some importance in the early years but are now not used to any extent (Wilson, 1984).

Numbers and Distribution

There were an estimated 18.5 million camels in the world in 1993 (FAO, 1995). Of these, probably 16.5 million were one-humped camels in the tropics and subtropics. More than 80% of all Arabian camels are found in Africa (Table 11.1) and East Africa contains about 63% of all Old World Camelidae. Somalia and Sudan account for 70% of camels in Africa while Ethiopia, Chad and Kenya contain a further 12%. In addition to these countries, Mauritania, Niger and Mali have rather large numbers and there are populations of camels in the Maghreb countries of Algeria, Morocco and Tunisia. In Asia, about 70% of one-humped camels are in India and Pakistan. Most Bactrian camels are found in Mongolia (both the Republic of Mongolia proper and the Inner Mongolia Province of China).

Table 11.1 Numbers and importance of the one-humped camel in some selected countries.
(*Source*: adapted from FAO, 1995.)

Country	No. (000)a	Percentage of world population	Density (No./km2)b	No./personc
World	1 8831			
Egypt	130	0.69	0.13	0.00
Ethiopia	1 000	5.31	1.00	n.a.
India	1 520	8.07	0.51	0.00
Israel	10	0.05	0.05	0.01
Kenya	815	4.33	1.43	0.04
Morocco	36	0.19	0.11	0.00
Niger	370	1.96	0.29	0.05
Nigeria	18	0.10	0.01	0.00
Pakistan	1 121	5.95	1.45	0.02
Saudi Arabia	415	2.20	0.02	0.07
Somalia	6 000	31.86	9.56	0.97
Sudan	2 850	15.13	1.20	0.19

a Includes Bactrian camels estimated at about 2 million in world total.
b Area used to calculate density is total land area.
c Figure used to calculate ratio to people is total agricultural population.

There was a steady increase in numbers during the 1960s, 1970s and the first half of the 1980s. Numbers in India increased from 0.65 million in 1945 to 1.1 million in 1985, most being in Rajasthan where they represent 9.9% of the domestic herbivore biomass, are present at a density of 3.1/km2 and there is one camel to 4.8 people. Where numbers have decreased they have done so for two largely unrelated reasons. In countries in which oil is now the principal commodity, and where the nomadic way of life is no longer the major one, there was a steady decrease in the number of camels in the middle of the twentieth century (although these may now be increasing again). Similarly, there has been a reduction in numbers of the Bactrian camel largely because it was perceived by the rulers of socialist and centralized economies as a sign of backwardness and lack of economic and social progress. The second reason for reduction in numbers was the severe drought conditions of the 1970s and 1980s over much of the range of the one-humped camel although losses of camels, compared to other classes of domestic stock, were minimal.

Types and Breeds.

Bactrian camels are distinguished by two humps of fatty tissue, a thick woolly coat that is usually reddish brown in colour, a deep fringe of hair under the neck and the possession of relatively shorter limb bones than one-humped camels. One-humped camels tend to be taller than the Bactrian and have less hair that is generally fawn or beige in colour (although other colours do exist as well as there being some two-coloured animals).

Largely as a result of the nomadic way of life under which most one-humped camels are reared, there has been relatively little differentiation into specialized types (Novoa & Wilson, 1993). There has also been much less morphological distinction, especially with regard to colour although there are some pied camels and in Saudi Arabia several colour types are described as 'breeds'. It is also possible to distinguish many

Table 11.2 Principal physical characteristics of lowland and mountain camels. (*Source*: Wilson, 1984.)

Characteristic	Camel type	
	Lowland	Mountain
Overall	Large	Small
Withers height (m)	1.932.13	1.821.96
Conformation	Rangy	Compact
Neck and legs	Long	Short
Hindquarters	Light, sloping	Well developed
Feet	Oval, usually soft	Round, hard
Coat	Short, fine	Long, coarse

different morphological types in Africa (Fig. 11.2).

Lack of specialization in production functions can be attributed to the uniformly harsh conditions in which camels are bred and reared and therefore their owners' requirements for them to be multi-purpose. If, indeed, specialization has occurred it is in the dichotomy of riding and pack types (Leese, 1927) with both of these being within the overall transport function. A further early classification allows camels to be classed as lowland or mountain types (Table 11.2). Lowland types are generally larger and less compact than the smaller and hardier mountain types.

Classification Systems

Early classifications almost certainly reflect ignorance at the time of the real role of camels in the life of those who owned them. They take little account of the ecological and social conditions under which camels were raised. In addition there is inadequate attention to the main productmilkin many areas and they are more concerned with the potential as transport and pack animals for colonial administrations.

A recent attempt to categorize camels into 'conventional' types comparable to those applied to cattle (Wardeh *et al*., 1991) proposes four classes: beef, dairy, dual-purpose, and racing. There appears little justification for this classification at present especially as, except in some experimental lots, no camels are reared pri-

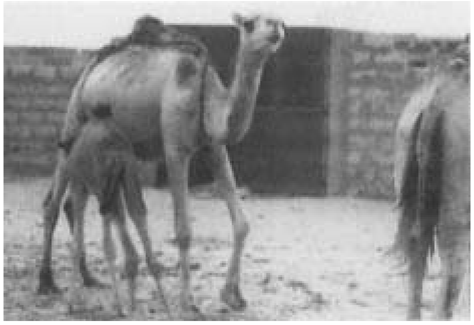
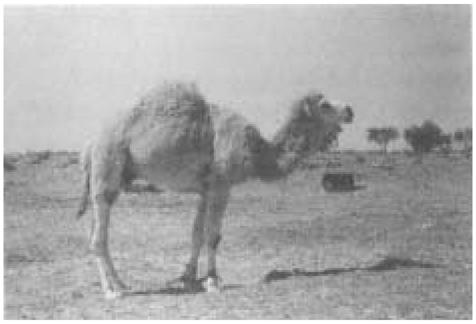
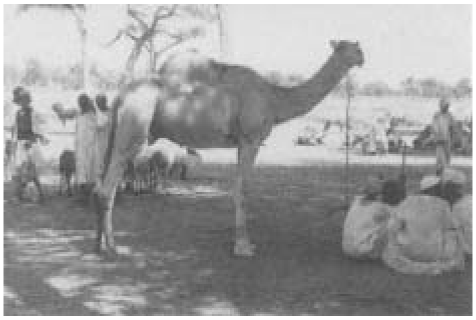


Fig. 11.2
Camel breeds of Africa: female Maure at Nouakchott



Stud Tunisian bull at the Institut des Zones Arides at Medenine

Female Mudugh of Somali origin in northern Kenya



Male Kababish baggager at Zalingei in western Sudan.

marily as meat producers; racing camels do not constitute separate breeds but are selected from within existing populations only after they have shown an aptitude for speed; and there is no provision for the still important transport role.

It has been said (Mason, 1984) that no true breeds are recognized and camels are named after the tribes that rear them. Earlier (Leese, 1927) it was said that 'wasms' or tribal brands were important in Arabia, Egypt and Sudan and that types could be identified by their help. Many modern classifications have advanced little on these concepts and are simply tribal or locational names, with little attempt to assign the production parameters, that are now so important in other domestic species, to the breed description.

One recent concept adopts a more quantitative approach (Blanc & Ennesser, 1989). It uses six morphological (with physical size based on a series of different measurements as the main one) and biological characteristics, habitat, function and geographical distribution to describe 'the 48 main breeds' of the one-humped camel. It assigns camels to nine regions and subregions in three main groups and eight (or nine) subgroups.

Such a classification has the merit of attempting to be quantitative and discriminating. It is doubtful, however, if the majority of workers interested in breeds would limit their number to 48 distinctive or main ones or even limit themselves to the classificatory variables employed. In Somalia, for example, a useful typology of three breeds not previously reported has included ease of milking and rapidity of weight gain as parameters in the breed description (Mohamed Ali Hussein, 1987).

Other recent classifications have included nine separate breeds for Algeria alone (Wardeh *et al*., 1991) and more than 20 in Arab Africa (Blanc & Ennesser, 1989), of which only two were from Algeria. The confusion inherent in present attempts to assign camels to breeds is clear in a comparison of these two systems where Wardeh *et al*. consider the Algerian Oulad Sidi Al-Sheikh to be of the dairy type while Blanc & Ennesser consider it a riding type. In Saudi Arabia, as already indicated, the commonly used classification is based on body colour. The relative proportion of a colour varies from region to region depending on the selection process but it is not clear whether these are true breeds or whether there are production differences between or among the colour types (Wilson & McKay, 1993).

A further modern approach lays emphasis on the indigenous knowledge of camel-owning groups. One example of this identified a breed from Madhya Pradesh, India, characterized by its milk production potential and provided details of its distribution area, population size, physical characteristics and production system (Köhler-Rollefson & Rathore, 1995). An almost infinite number of 'breeds' could be described using this methodology but it does have the benefit of tracing the evolution of distinct populations of animals and describing the social and historical factors contributing to their formation. Possible threats to the existence of some of these breeds and to continued genetic diversity can also be evaluated in the field.

In the former Soviet Union all one-humped camels are of the Arvana breed (Turkmen = purebred). This is described as a dairy, transport and riding type whose qualities have been achieved through a long period of selection (FAO, 1987).

Hybrids of Camelus dromedarius *and* Camelus bactrianus

The current taxonomic positions of the one-humped and Bactrian camels arise historically from the belief that hybridization between the 'species' was not possible. Once this fallacy had been disproved it was then assumed that the offspring of interspecific mating were infertile, as are the mule and the hinny from the donkey/horse or the reciprocal cross and as are many yak/cattle hybrids. This premise has also long been proved false and there is no reason, other than established usage, to maintain the species distinction.

Crosses were probably first made about 2200 BP. Hybrids have been known for a very long time in Turkey, in northern Iran and in Afghanistan where they have specialized roles. Organized hybridization was still important in Turkey in the 1920s when up to 8000 one-humped females were imported from Syria and farther south to be served by Bactrian males (the total number of camels in Turkey in 1997, probably all of the Bactrian type, did not exceed 2000).

Most research on crosses between one-humped and Bactrians has been in the former Soviet Union (Auelbjekev, 1967). The usual cross is a Bactrian male on a one-humped female. The F1 hybrids are almost always fertile with normal male spermatogenesis. First generation females, when bred back to one or other of the species, drop offspring resembling the male parent, whether one-humped or Bactrian. The F1 shows heterosis in body size, hardiness, endurance and longevity. Some Bactrian characters, such as the hairy beard and legs, are retained and the single hump (often with a small indentation to the front) is longer and less well developed than in the one-humped camel. This is a strong draught animal whose wool yield tends toward the Bactrian. Milk yield and fat content are intermediate between the parents. Further crosses are sometimes made and, in the Former Soviet Union, each has a name but in practice crossing is confined to the 'bertuar' (*Camelus bactrianus* × *Camelus dromedarius*) or, less commonly, to the 'kerspak', a backcross to the Bactrian. Other crosses, particularly those from *inter se* F1 matings, produce weaker animals that have reduced hybrid vigour and poor conformation and are difficult to train.

Adaptation

The camel's exceptional tolerance of heat and of water and feed deprivation are well known and admired. Some of the tolerance is associated with the differences in anatomy and physiology between camels and true ruminants (Table 11.3). Other aspects of tolerance are related to behaviour. As a result of these three types of adapta-

Table 11.3 A comparison of some characteristics of camels and true ruminants. (*Source*: adapted from Fowler, 1997.)

Characteristic	Camels	Ruminants
Evolution	Evolutionary paths diverged about 40 million years ago	
Blood	Red blood cells elliptical and small (6.5 µm); predominant white blood cell = neutrophil, leucocytes up to 22 000	Red blood cells round and larger (10.0 µm); predominant white blood cell = lymphocyte, leucocytes up to 12 000
Foot	Toenails and soft pad; second and third phalanges horizontal	Hooves and sole; second and third phalanges almost vertical
Digestive system	Foregut fermenter with regurgitation, rechewing and swallowing; 3-compartment stomach, resistant to bloat	As for camel (parallel evolution); 4-compartment stomach, susceptible to bloat
Dental formula	(Incisors 1/3, canines 1/1, premolars 12/12, molars 3/3) × 2 = 2832	(Incisors 0/3, canines 0/1, premders 3/3, molars 3/3) × 2 = 32
Reproduction	Induced ovulator; follicular wave; copulation in prone position; diffuse placenta; cartilaginous projection on tip of penis; prolonged ejaculation	Spontaneous ovulator; oestrous cycle; copulation in standing position; cotyledonary placenta; no cartilaginous projection on tip of penis; short intense ejaculation
Respiratory system	Elongated soft palate, primarily nasal breather	Short soft palate, nasal or oral breather
Urinary system	Smooth elliptical kidney; female has suburethral diverticulum at external urethral orifice; male has dorsal urethral recess at junction of pelvic and penile urethra	Smooth or lobed kidney; female lacks suburethral diverticulum at external urethral orifice; male lacks dorsal urethral recess at junction of pelvic and penile urethra
Parasites	Unique lice and coccidia, common gastrointestinal nematodes	
Infectious diseases	Minimally susceptible to tuberculosis; mildly susceptible to foot-and-mouth disease; no known natural bovine brucellosis	Highly susceptible to tuberculosis, foot-and-mouth disease, and bovine brucellosis

tion, the one-humped camel is almost certainly the domestic animal best adapted to the harsh, dry and fluctuating nutritional conditions of the arid and extremely arid zones.

In summary (with details being provided in the subsequent sections) the superior tolerance of camels to the desert environment stems principally from:

- A relatively efficient sweating mechanism for heat dissipation.
- An ability to reduce faecal and urine water loss.
- The ability to allow substantial changes in deep body temperature.
- Behavioural responses that reduce heat absorption.

Anatomy

The large size of the camel is itself an anatomical advantage in hot conditions as it results in a smaller relative surface area to total body mass. The relationships of body weight to energy expenditure and the required water loss to preserve a constant body temperature are well known (Schmidt-Nielsen & Schmidt-Nielsen, 1952; Schmidt-Nielsen, 1965), with heavier weights providing enormous advantages (Fig. 11.3). The long thin legs and neck of the camel are further adaptations to desert conditions, as is the hump. Fat concentrated in the hump and not generally distributed over the whole body surface allows rapid dissipation of heat through the skin when required.

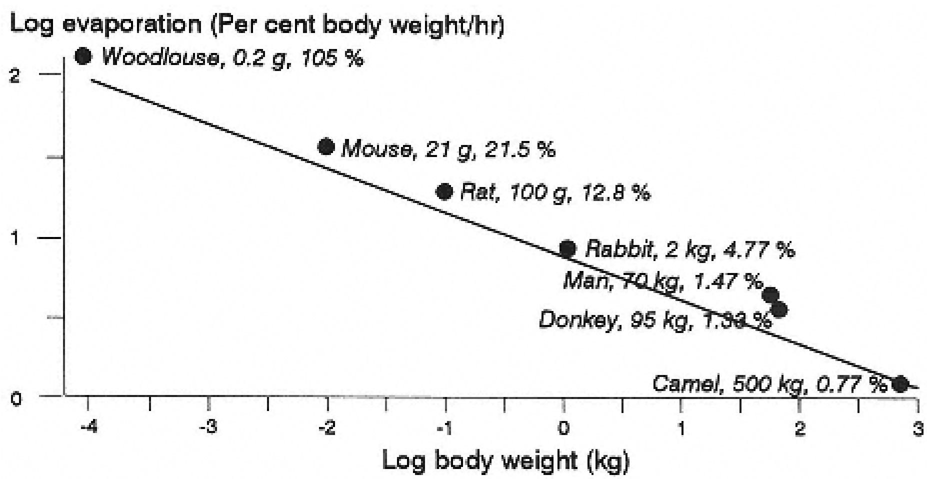


Fig. 11.3
Relationship between body weight and required water loss to maintain a constant body temperature in desert animals.
(Source: Schmidt-Nielsen & Schmidt-Nielsen, 1952.)

The large pad-like feet reduce ground pressure when walking and allow easy progress over sand. Massive supra-orbital processes (the prominent bone above the eye) protect the eye from the direct rays of the sun. A prehensile and mobile split upper lip allows the camel to select the most succulent and nutritious feed portions from the total on offer.

Physiology

Body Temperature

A major physiological adaptation of the camel is its ability to allow its body temperature to fluctuate. The normal diurnal variation in a fully hydrated camel does not exceed 2°C in the range of about 3638°C. In dehydrated camels, when considerations of energy and water conservation become more important, temperature variations are usually about 6°C but they can be as much as 8°C in the range 3442°C. These extremes are outside the range of comfort of most mammals and would be lethal for many. There is a much wider variation in temperature in the camel than in the donkey or in man. A temperature range of 6°C in a 500 kg camel enables 1.26 × 107 J of energy to be stored (compared to 4.2 × 106 J for a 2°C variation), equivalent to the conservation of about 6 litres of water if sweat had to be used to dissipate the same amount.

A reduced temperature gradient between the camel and the air assists further in reducing heat gain, as the gain is proportional to the gradient. Heat stored during the day is dissipated when ambient temperatures are cooler at night. The combined strategies of a high body temperature during the day and heat loss at night allow the water required to maintain a temperature within the acceptable range for the camel to be reduced from 4.7 to 1.4% of the body water pool.

In fully watered camels thyroid activity is higher in summer than in winter but activity is reduced in camels deprived of water. This is important because generation of metabolic heat is lessened and respiratory water losses are reduced. Chronic exposure to heat results in depressed thyroid activity as well as reduced plasma cortisol and growth hormone concentrations and turnover rates. All three sources normally create heat and act together so the net result of habituation to heat is some reduction in metabolic rate.

At very high temperatures and constant heat loads even camels need to dissipate heat. Many mammals achieve evaporative cooling through increased respiratory rates rather than by sweating. Respiratory cooling is relatively more ex-

pensive in water than sweating as faster respiration needs more energy. Normal rates in camels are in the range 611 breaths/min (average = 8) in the Sahara. Under heat stress these increase only to 818 (average = 16) but these do not result in significantly increased evaporation. Camels avoid energy expenditure, when they need to use water for cooling, by sweating but they do not sweat continuously as do many other mammals and sweat evaporates directly from the skin. The latent heat of evaporation is therefore taken from the skin rather than from the coat surface.

Dehydration

A reduced water supply can be tolerated by a number of species of desert-adapted ruminants and under these conditions its use becomes more efficient. Efficiency of use and dehydration tolerance vary among species. Under the same conditions cattle lose water three times faster than camels (equivalent to 6.1% of body weight per day at day/night temperatures of 40°C/25°C) and sheep at two to 2.5 times (45% of body weight). Cattle would die in 4 days at a total weight loss of 2832%, sheep in about 7 days, and camels would survive 15 or more days, mainly because camels do not lose appetite with dehydration. Bedouin goats are capable of sustaining reductions in body weight of up to 35% but lose water much more rapidly than camels.

Sources of water loss for camels are about 50% from the alimentary tract and intracellular spaces and 50% from the interstitial spaces, with very little change in the water content of body solids and plasma. In cattle, losses are about equally divided on the one hand amongst body solids, alimentary tract and intracellular spaces, and on the other between interstitial spaces and plasma.

Fully watered animals usually have about 16% of the body water pool in the plasma. Following dehydration cattle lose about 20% of plasma volume. A major part of the camel's ability to withstand water deprivation arises from its ability preferentially to conserve plasma volume which under severe dehydration is reduced by only 5%. The volume is maintained by absorption of water from the alimentary tract where there may be a reduction of as much as 82%. There is no rise in packed cell volume (PCV) in camel blood as a result of volume depletion, largely due to the peculiar resilience of camel red blood corpuscles which are capable of reverting to their original size and shape even after severe compression.

Rehydration consists of not only the act of drinking but also the absorption and distribution of water throughout the body tissues. Ruminants in general, because of the large buffering capacity of the alimentary tract, are able to drink large quantities of water in a very short time after a period of privation. Animals without this capacity are rarely able to take all their water requirements at one short session, mainly due to the problems associated with haemolysis. Some non-ruminants are, however, capable of rapid drinking, including dogs and donkeys. Even amongst the group of animals that drink rapidly the camel is peculiar in being capable of absorbing all the water almost immediately into the bloodstream. After 4 hours water is in equilibrium throughout most body tissues and normal intake resumes. Kidney function has also returned to normal after 4 hours and the erythrocytes return to their normal size and shape.

An early and most important aspect of dehydration on metabolism in most animals is a reduced food intake. Even when food is abundant a reduced water intake inhibits and depresses the amount eaten. The two principal causes for less food being ingested appear to be a reduction in the flow of saliva from the parotid glands and changes in the rumen flora leading to less efficient digestion, particularly of nitrogen. In the camel the normal salivary flow of about 80 litres/day is reduced by 80% to about 16 litres/day when dehydrated. It appears that this amount is sufficient to maintain the appetite of camels under severe dehydration.

Water Turnover

Low water turnover is characteristic of arid-adapted ruminants (Schmidt-Nielsen *et al*., 1957). This allows longer times between drinking and thus enables better use to be made of sparse desert grazing. Low turnover rates in heat-stressed and dehydrated animals are associated with a reduced metabolic rate. The two most significant factors contributing to water turnover in animals at maintenance or under low production levels are the requirements for evaporative cooling and the need to ensure adequate food intake. Lactating camels use water at 50% higher rates than dry animals and turnover rates are increased for animals carrying heavy loads. Water turnover rates also vary with environmental conditions.

Research in the Turkana district of northern Kenya (Coppock *et al*., 1988) has underlined not only species differences but also changes in response of species to water availability in different seasons (Fig. 11.4). Rates of water consumption in camels were only 3470% of those of other species and did not differ between dry and wet seasons. Consumption rates for donkeys did

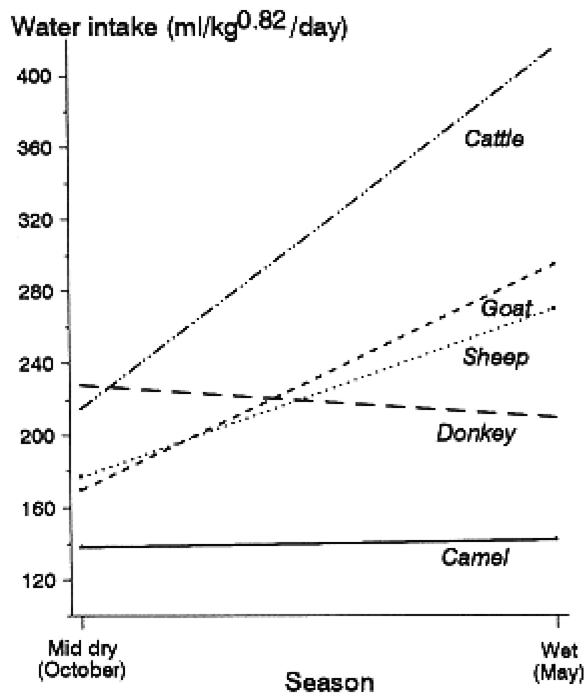


Fig. 11.4
Water consumption by various species of domestic livestock in Turkana district, Kenya.
(Source: Coppock *et al*., 1988.)

not differ between seasons but sheep (53%), goats (77%) and cattle (94%) drank much more in the wet season than in the dry. Cattle water consumption was increased in the wet season as a result of more frequent watering whereas goats and sheep drank larger volumes at each drinking but were watered less frequently.

Water Loss.

Respiratory Evaporation

Many animals respond to a hot environment by an increased respiration rate and, in some cases, open-mouth panting. Respiration in the camel increases very little with increase in ambient heat load and the respiratory route is a very minor source of water loss. Camels are also able to exhale unsaturated air under some conditions. The combination of cooling and desaturation can result in a saving of 60% of the water that would be present in fully saturated air exhaled at body temperature. A lower rate of breathing at night also increases the tidal volume of air and the amount of oxygen extracted thus further reducing water loss.

Cutaneous Evaporation

Some water moves through the skin by insensitive diffusion. Most of the water that passes through the skin, however, does so in the form of active sweating. Larger mammals usually sweat to dissipate heat and both camels and cattle have adopted this strategy. The main source of evaporation in the camel is via the skin but there is no copious flow of sweat or obvious wetting of the hair. Evaporation takes place at the skin surface and not at the extremities of the hair and the latent heat of evaporation is therefore drawn from the skin rather than from the atmosphere.

Faeces

In fully watered animals considerable amounts of water are excreted with the faeces. The total amount of faeces and their water content vary according to the type of food and its digestibility. Ruminants are normally able to extract considerable water from the intestinal contents but this process is very much more efficient in arid-adapted animals when dehydrated. All species of domestic ruminants can reabsorb a greater proportion of gastrointestinal water when dehydrated while at the same time increasing the electrolyte concentration in the retained fluid. The overall response to dehydration by ruminants is a reduction of 1035% of faecal water with the camel being among the most efficient (Table 11.4) although in most ruminants faecal water loss is a considerably lesser proportion of total loss than that from evaporative cooling.

Urine and Kidney Function

The ability of the kidney to concentrate urine is an important factor contributing to survival in arid lands. The normally low urine volumes voided by the camel are reduced further under dehydration and a relatively high total osmolarity (i.e. the concentration of solutes) is further increased. In relation to body weight, camels pass very little urine even when they have free access to water and the total amount rarely exceeds 5 litres/day. In addition to the small

Table 11.4 Water contents of faeces of domestic ruminants when fully watered and when dehydrated. (*Source*: Wilson. 1989a (from various other sources).)

Species	Water content (g H_2O/100 g dry matter)		
	Fully watered	Dehydrated	% decrease
Camel[a]	109	76	30
Camel[a]	268	168	38
Temperate cattle[b]	362	302	17
Goat[c]	140	88	37
Goat[b]	132	106	20
Sheep[b]	134	93	31

a Natural conditions.
b Climate chamber at 22°C/40°C.
c Climate chamber at 18°C/30°C.

amount excreted the camel has another peculiarity which consists of frequent urinations each of very small volume (indicating that the camel bladder is very small). The camel's habit of urinating on its legs is an additional adaptation to the desert as it does cause some evaporative cooling.

Several studies have shown the reduced function of the camel kidney under dehydration including a reduction in glomerular filtration rate from about 60 ml/100 kg/min to 15 ml/100 kg/min. When camels are allowed to drink immediately to satiation the kidney function rapidly returns to normal. Within 30 minutes there is a significant increase in urine flow rate, in glomerular filtration rate and in kidney plasma flow and these are accompanied by significant decreases in plasma and urine osmolarities.

Behaviour

Water and temperature control in the camel are assisted by many aspects of its individual and group behaviour. Principal among these, at least when allowed to express its own inclination, are a preference for feeding at night, in the early morning or late evening, or when the sky is clouded over. If the camel is allowed to feed at night it couches early in the morning before the sun has warmed the ground, thus reducing heat absorption by conduct from the earth to its body. It also tucks both fore and hind legs beneath it to reduce contact with the ground, unlike cattle which lie in closer contact with the substrate. This method of couching eliminates yet another conductance path. Standing or sitting, the camel gradually shifts its position throughout the day to keep in line with the sun so reducing the area subject to direct radiation.

When herded in groups and allowed to rest camels invariably cluster together if conditions are hot, which again reduces the total area subject to radiation. Sheep also adopt this strategy under hot conditions but, unlike sheep which cluster with their heads central to the unit, camels prefer to orient (as they do as individuals) to the sun and move position as it rotates across the sky.

Reproduction

Much research in recent years has concentrated on the anatomy and physiology of reproduction (Merkt *et al*., 1992) with little emphasis being given to the practical aspects of reproductive performance. The one-humped camel is generally considered to achieve puberty at relatively advanced ages in both sexes, particularly under traditional management. Intervals between successive parturitions are long in most areas. The pattern of births is often markedly seasonal and is probably related to nutritional and management factors.

Male

Anatomy

The sheath or prepuce is large, fleshy, triangular in shape and laterally compressed. A well developed lateral preputial muscle, along with the normal caudal and cranial muscles, directs the penis towards the rear when urinating but towards the front at erection for copulation (Degen & Lee, 1982). The internal lamina of the prepuce is fused to the penis by loose connective tissue. At sexual maturity at about 3 years of age the penis becomes free of the prepuce under the action of testosterone.

The scrotum is small both absolutely and relative to the camel's size. It is attached just below the ischial arch, is not pendulous and not distinctly divided into two compartments. An important role of the vascular, as opposed to the muscular, tissue is implied for testicular cooling by this arrangement. The testes have already descended into the scrotum at birth but are very small until 3 years of age, following which a spectacular increase in weight and volume occurs. In addition to age changes in weight there are seasonal ones related to the breeding period (Singh & Bharadwaj, 1978). The seminiferous tubules are divided into three zones. The major part is tightly coiled and is the site of sperm production. There are seasonal changes in the diameter of these tubules. The epididymis is attached to both ends of the testes and is the site of sperm maturation in its initial and middle parts and of sperm storage in its terminal part. The camel has no seminal vesicles.

The penis is of the fibroelastic type with a marked prescrotal sigmoid flexure. The erectile tissue comprises many venous spaces of various sizes that contain elastic fibre but no muscular tissue. The cranial end of the penis, on which there is no true glans penis, is sickle shaped.

Physiology.

Under most conditions male camels reach puberty at 34 years but in exceptional cases this can be achieved at 2 years or less. Spermatogenesis is continuous throughout the year but in many areas activity varies with season. Sperm production is about 41 × 106 per g of tissue at 34 years and rises to a peak of 120 × 106 at 67 years. Male camels show a strong behavioural rut when they are in breeding condition. The physiological changes associated with this are an increase in androgens in the blood from a basal level of less than 3.8 ng/ml to one of 1735 ng/ml.

Mating Behaviour

Rut induces a radical change in behaviour resulting in aggressiveness toward other camels and, often, to handlers. A rutting male grinds his teeth, waves his head and neck about, moves restlessly, froths at the mouth, lashes his tail and urinates frequently with the urine being splashed about by the tail. Diarrhoea often accompanies the rut and may contribute to the loss of condition in male camels at this time. There is a strong dominance hierarchy in camels, one male imposing supremacy over subordinate animals which quickly lose libido and go out of rut. Poll glands increase in size during the rut and secrete a sticky dark fluid with an androgen concentration similar to that of the blood. A characteristic feature of the rut is the extension of the soft palate or 'dulaa'. The palate is filled with air from the lungs and it is possible that its protrusion and the accompanying gurgling sounds are attractive to the female.

Male camels sniff and bite the vulva and other parts of the body of females prior to attempting coitus which takes place in a recumbent position. Females in oestrus often couch readily but may have to be forced down by the male who usually achieves this by pressure on the neck and hump. Many traditional camel-owning societies assist the male with intromission but this is usually effected naturally by rotational movements of the penis until the vulva is found. Penal strokes are not violent. The sex act, which lasts as long as 35 minutes, comprises several entries and males may exhaust themselves on one female if not restrained. Both sexes, but especially the male, are noisy during the act.

Female

Anatomy

The vulva is 35 cm deep with thick velvety lips and the clitoris is very small. The urethra is short and the opening of the urinary meatus is narrow. The cervix consists of out-growth ridges arranged in three or four rows. The vagina is some 3040 cm in length and lined with mucosal folds; it is wide and extensible and with advancing pregnancy the uterine weight tends to stretch the mucosal folds. The oviducts, which are 1728 cm in length, follow a tortuous course to the horns but more so in the ovarian part of the Fallopian tube and the ampulla than in the isthmus. They are soft and flabby except in the area of the isthmus where there is a thick, fibrous muscle layer. Unlike other mammals the oviducts are enlarged at the uterine end, this unique arrangement allowing prolonged storage of large numbers of spermatozoa.

The camel has a bicornate uterus which is T-rather than the normal Y-shaped. The body is short, reddish in colour and smooth, the left horn being longer than the right. The uterus is usually abdominal in position and increases in weight during follicular activity. The placenta is diffuse and epitheliochorial in nature, without cotyledons. The ovaries are flattened, lobulated and reddish brown in colour and each is enclosed in an ovarian bursa which is similar in structure to that of other domestic animals but, unlike buffaloes and cows, medullary tubes (normally seen only in the embryos of these two species) are present in four out of five camel ovaries. The size of the ovary is 15 mm × 30 mm and its weight is 515 g. Non-functioning ovaries may weigh as little as 3.7 g, those with Graafian follicles 5.5 g and those containing a corpus luteum of pregnancy about 8 g. Graafian follicles occasionally persist into pregnancy but in non-pregnant females are distributed randomly over the ovarian surface. They are opaque and spherical and up to 18 mm in diameter. Ovarian activity is follicular rather than luteal and a corpus luteum is usually seen only during pregnancy.

The udder has four quarters, the front two being separated more distinctly from each other than they are from the two smaller rear quarters. The udder is covered by a thin black skin. The teats are small and have three small openings.

Physiology

The Follicular Wave

Camels are not spontaneous ovulators and a stimulus is required for release of the ova. This type of cycle involving reflex or induced ovulation is properly known as a follicular wave (Fig. 11.5). In induced ovulators, and particularly in the camel, there are four distinct phases of the reproductive cycle (as there are in spontaneous ovulators) but the terminology normally used for spontaneous ovulators is not appropriate. The four phases of the follicular wave in camels are:

- The mature follicular stage, equivalent to oestrus or heat. (The camel should not be considered to be in continuous oestrus in spite of the fact that ovarian maturity is follicular. Unlike rabbits, which accept the male at any time, female camels accept the male only during the mature follicular stage. There is no normal luteal phase).

- The atretic follicular stage, during which the follicle regresses, starts after a varying period of time if mating does not occur.

- The non-follicular stage.

- The growing follicular stage.

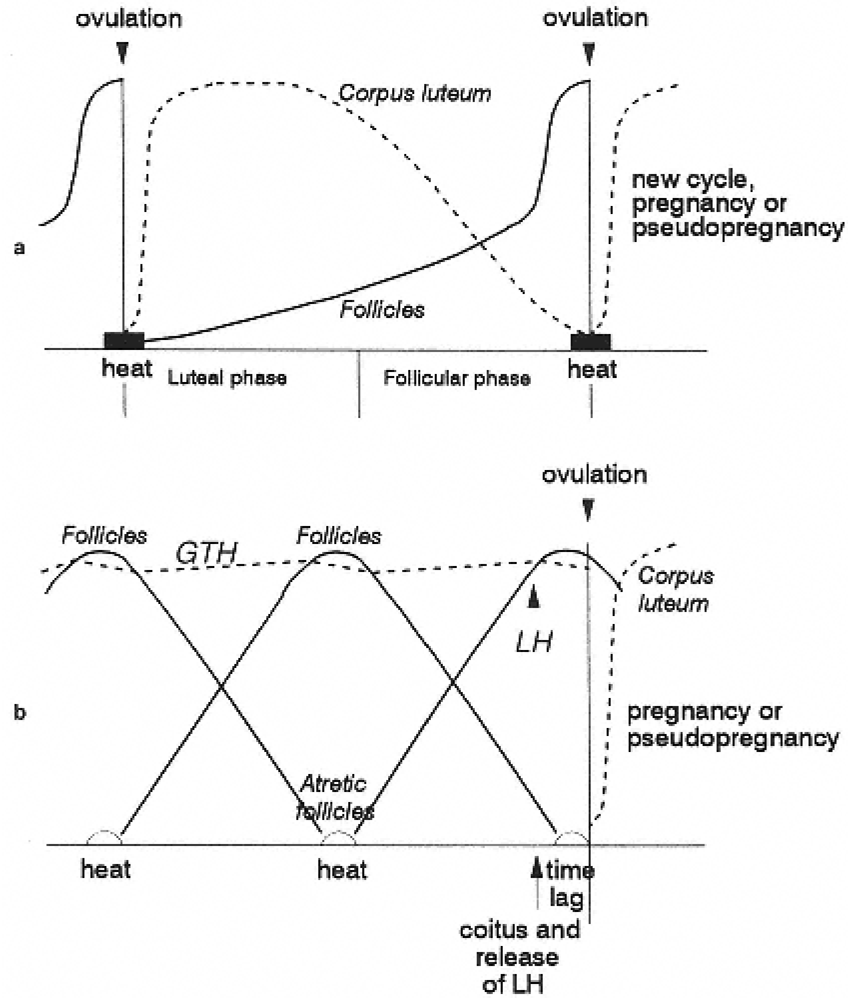


Fig. 11.5
A comparison of events in the sexual cycles of (a) spontaneous and (b) induced ovulators.
(Source: Nalbandov, 1976.)

Progesterone levels in camels at oestrus are about 0.5 ng/ml while oestrogens are at a peak of 75 pg/ml (Marie & Anouassi, 1987). The level of oestrogen rises to 3.5 ng/ml at day 36 and then to a peak of 4.5 ng/ml at day 9 in mated camels, before falling rapidly: oestrogen levels drop to 15.1 pg/ml at the first stage and remain low. The concentration of luteinizing hormone rises rapidly to a maximum of 6.9 ng/ml from a basal level of 2.7 ng/ml, starting 1 hour after coital (or other) stimulation, reaching a peak at 3 hours and remaining high for about 10 hours. Ovulation occurs 3648 hours after mating.

Duration of the Wave, Polyoestrus and Seasonality

In most areas follicular wave activity occurs all year round but the length of the whole wave, the phasing and the duration of oestrus vary considerably. In areas where there is marked climatic seasonality follicular activity is at its greatest in winter and spring and the total cycle is longer at this period (Fig. 11.6). During the summer mature follicles are found in only a few animals (i.e. the phase lasts for only a very short time) and the growing follicular stage is relatively prolonged.

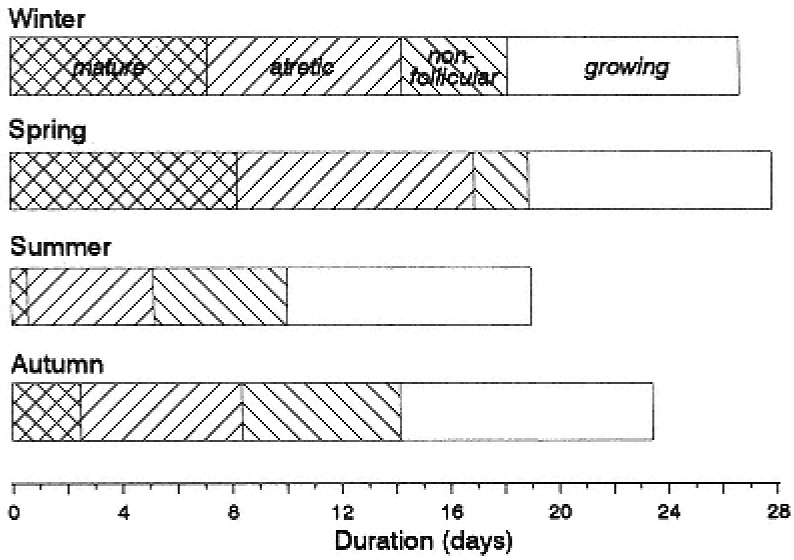


Fig. 11.6
Total and proportional times of phases of the follicular wave in Egyptian camels.
(Source: Nawito *et al*., 1965.)

In Egypt the mean duration of the follicular wave is 24.2 (range 1135) days with oestrus lasting 4.6 (015) days. These figures are confirmed by work both in Sudan where the length of the wave is 28 days with oestrus normally lasting 46 (17) days and in India where wave duration is 23.4 days and oestrus averaged 5.0 (36) days. The female accepts the male at the end of oestrus when the follicles are mature. If she is not mated ovulation does not take place and the follicle is reabsorbed over a period of 213 days. The process is similar in the Bactrian camel (Chen & Yuen, 1984b).

Pregnancy and Parturition

Following successful mating the corpus luteum develops rapidly achieving greatest weight and size at 60 days, then remaining about this size throughout pregnancy. It appears that a corpus luteum is required for pregnancy to be maintained. The left ovary is usually more active than the right in the ratio of about 55:45 of eggs shed. The site of pregnancy, however, is almost invariably in the left ovary, indicating that ova or embryo migrations occur. Double (about 1315%) and triple (about 12%) ovulations are not uncommon but two fetuses are rarely supported longer than a few days and early embryonic loss is of the order of 15%.

Early data on the duration of pregnancy were conflicting, anywhere between 345 and 405 days. It is now well established that pregnancy in the one-humped camel is about 387 days (Wilson, 1986b, 1989b). In Bactrian camels it seems that pregnancy is slightly longer in the range 380420 days (Chen & Yuen, 1984b). The hormonal mechanisms initiating parturition are not well known. The process lasts about 56 hours in most cases but is usually shorter in those dropping their first young. The initial stage, or let down, is the longest. The actual birth is usually very rapid and expulsion of the afterbirth generally does not exceed 30 minutes.

Camels do not lick their young following birth nor do they eat the placenta. Uterine involution is completed somewhat more quickly in primiparous females than in older animals, in which it takes about 40 days. The timing of the first postpartum oestrus and its intensity are very variable and probably related to the time of year, nutritional status and management.

Mating Behaviour

There are anatomical, physiological and behavioural signs of heat. The intensity of heat varies

both individually and seasonally. In India, for example, 14, 31 and 55% of female camels exhibit weak, moderate or intense signs, respectively.

Camels in heat become restless, bleat continuously and associate with the male; the tail is lifted and flapped and they urinate little and often. The lips of the vulva swell, and open and close irregularly. There is usually a copious flow of mucus that is foul smelling to humans but presumably a powerful and attractive olfactory stimulus for the male camel.

Artificial Insemination.

Artificial insemination has been used successfully in both one-humped and Bactrian camels but still presents some practical problems on a large scale because of the difficulties of inducing ovulation (Anouassi *et al*., 1992) and maintaining quality in frozen semen (Chen *et al*., 1993). In addition semen collection using an artificial vagina is not always successful due to the limited protrusion of the penis. It is sometimes possible to induce ejaculation by massage of the penis or the pelvic genitalia but electro-ejaculation is a surer way of obtaining semen.

Pregnancy Diagnosis

Pregnancy can be easily diagnosed by rectal palpation once the fetus is 6 weeks old (Musa & Abusineina, 1978; Chen & Yuen, 1984a). New techniques using radioimmunoassay and enzyme-linked immunosorbent assay (ELISA) to measure hormone concentrations allow pregnancy to be diagnosed with a very high degree of certainty within a few days of conception (Combarnous & Anouassi, 1994).

Reproductive Performance

Age at First Parturition

Data from retrospective surveys to establish the reproductive careers of camels have provided indications of ages at first parturition. In traditionally managed herds in Kenya an age of 58 months has been estimated by the Integrated Project for Arid Lands (IPAL, 1985). Two studies from Niger give estimates of 63.4 months on a sample of 2610 camels (Richard *et al*., 1985) and 58.8 ± 19.2 months for 215 females (Wilson, 1989b). In the first Niger study 380% of females (varying with ethnic group and management type) first gave birth at 45 years. About 95% had produced at least one young at 6 years except in one transhumant group where a 95% level having given birth at least once was not reached until the 89 year age-group. In the second study the age range at first parturition was 211 years.

Animals of known age gave birth for the first time at 61 months in an experimental herd in Kenya (IPAL, 1985). In ranch herds in Kenya the average age at first parturition of 37 camels which had run freely with a male from birth was 54.2 ± 2.8 months, varying among ranches from 48.6 to 56.1 months (Wilson, 1986b). The youngest animal first gave birth at 45.6 months and the oldest at 71.3 months. Average age at first parturition of 105 Bikaneri camels on a breeding farm in Rajasthan was 61.0 ± 0.98 months (1838 ± 29.7 days) but it is not clear if there was control over the age at first service (NRCC, 1991).

Parturition Intervals

The conventional wisdom is that the interval between successive births is about 2 years. Retrospective studies in traditional systems tend to confirm this period but intervals vary and are often spread over a very long period (see Wilson (1989b) for sources). In Mali, of 43 cases reported in a Touareg herd, nine were between 13 and 15 months, 12 between 16 and 19 months, 19 of about 24 months and three of longer than 24 months. An early study in Kenya showed that only four of 26 intervals were of less than 24 months, fourteen were around 24 months and eight were 25 months or longer. In Kenya an interval of 26.8 months in traditional herds was reduced to 20.8 months when a veterinary package comprising routine treatment of tick and worm infestations, vaccination against anthrax and blackquarter, treatment of

trypanosomosis and other diseases, and a regular supplement of salt was implemented. A second traditional herd in Kenya had an interval of 28.4 months.

In Niger the average interval in three eastern provinces was 30 months with variations between sedentary (25 months in Maradi, 27 months in Zinder, 38 months in Diffa) and transhumant herds (24, 30 and 27 months in the three areas). Farther north in the Aïr region of Niger, in a Touareg traditional system, an interval of 26.2 ± 10.56 months was established for a total of 329 intervals. The interval varied among different parities. A study in southern Morocco showed an interval of 24 ± 8.2 months in the range 2051 months with peaks in the distribution of intervals at 12 month periods (Fig. 11.7).

Under commercial ranch management in Kenya (Fig. 11.7) the mean of 460 intervals was 18.7 ± 0.38 months (Wilson, 1986b). Parity did not influence the interval although there did appear to be slightly shorter intervals in higher parities (Table 11.5). An abortion or the death of

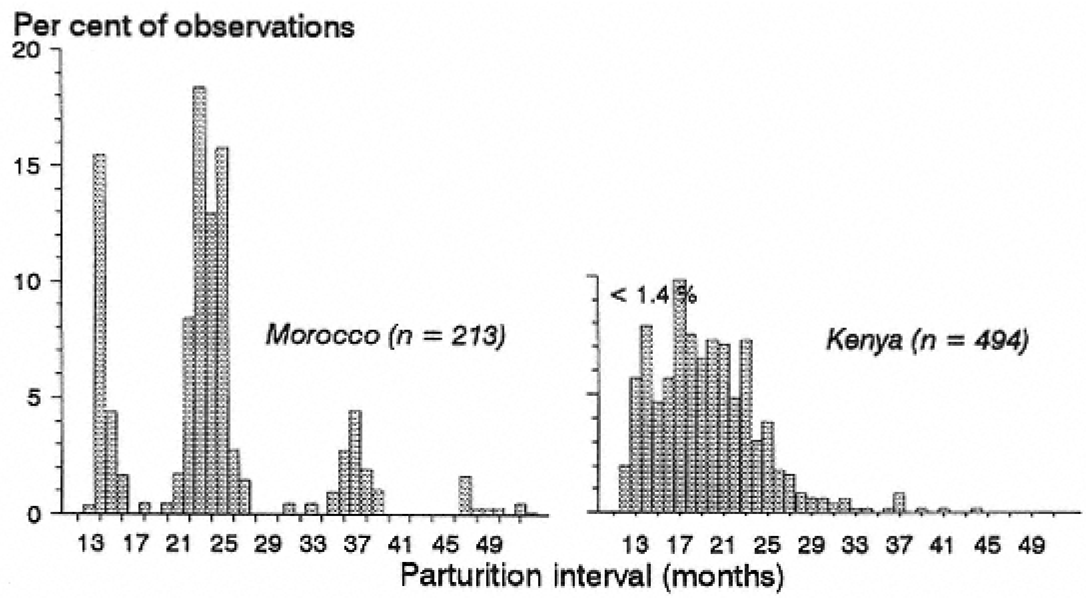


Fig. 11.7
Intervals between successive births in camels in Morocco traditional and Kenya ranch herds.
(Sources: Sghiri, 1987; Wilson, 1986b.)

Table 11.5 Effect of parity on birth intervals (months) in traditional and modern camel production systems. (*Source*: Wilson, 1989b.)

Interval	Country (system type)					
	Niger (traditional)			Kenya (modern)		
	No. observations	Mean	SD	No. observations	Mean	SD
12	144	28.6	9.10	190	19.3	0.48
23	97	24.0	9.63	149	18.3	0.51
34	54	25.8	8.89	77	18.8	0.66
>4	34	20.1	7.55	44	18.6	0.87

SD = standard deviation.

the young before weaning led to a shorter interval to the next birth compared to young survived to weaning. probably due to the effects of lactation on the reproductive hormones. In other studies the interval between births has been established as 14.3 months (434 days) in Najdi camels in Saudi Arabia and in commercial milk herds in the Al-Jouf region a calving interval of 1415 months has been achieved.

Annual Reproductive Rate

The annual reproductive rate (ARR) is equivalent to the number of young born per female per year. In northern Kenya 'calving percentages' were 21.1% for herds that received no veterinary treatment compared to 47.4% for those that did receive treatment. Calculated from the calving interval provided. the ARR would be 0.45 and 0.58 young per female per year. On the same basis the ARR on commercial ranches in Kenya would be 0.64. In southern Somalia an ARR of 0.78 in 1984 implies an interval between births of 15.4 months. For three Kenya populations using aerial survey methodology an ARR of 0.47 could be calculated with an implied birth interval of 25.5 months. In Darfur, in western Sudan, a calving percentage of 70 was estimated in 1977, with an implied interval of 17.1 months (ARR = 0.70). In retrospect, it seems probable that the rate in Darfur was due to rainfall fluctuations over the preceding years and probably represented a peak in productivity. In northern Niger the ARR was calculated as 0.46 young per breeding female. In eastern Niger age specific fertility rates varied from 0.01 to 0.57 at different ages.

Total Lifetime Production

In Niger a total of 215 camels had given birth to 573 young or an average of 2.7 per breeding female. Calculated from the age at first parturition and the average interval between parturitions, a female culled after 2.7 young would be aged about 10.8 years. In Kenya the average lifetime production of young was 3.5 per female on commercial ranches. Similar calculations of average production of young in eastern Niger showed that in nine different types of herd the average age and productivity of a breeding female varied from 7.6 years, having given birth to 1.9 young, to 8.6 years, having produced a maximum of 2.4 young.

Seasonality

Early empirical observations of the seasonality of breeding have been supplemented by abattoir studies and more recently by retrospective career histories and complete records. A summary of some of the literature data (Table 11.6) indicates a marked seasonality with most activity in winter in the northern hemisphere. Extended and irregular seasons are not uncommon, however, particularly when the camel is moved to areas outside its normal environment and range (Fig. 11.8).

In Somalia there appear to be two main breeding seasons related to the bimodal rainfall pattern but births occur all year. In Djibouti, the little information available also indicates opportunistic breeding, perhaps related to the proximity of both the low and erratic rainfall of the Red Sea winter precipitation zone and of the inland and highland summer zone of Ethiopia. In Kenyan traditional herds there is some breeding all the year round (as indeed there usually is elsewhere) but with apparently greater activity in December/January and May, possibly associated with better nutritional status at conception. On Kenyan commercial ranches, in spite of there

Table 11.6 Breeding seasons of the one-humped camel in various countries. (*Source*: Wilson, 1989b (from various other sources).)

Country	Breeding season
Egypt	DecemberApril
Egypt	MayAugust
India	NovemberFebruary
Mali	February/March + August/September
Morocco	MayJune
Pakistan	DecemberMarch
Somalia	AprilMay
Somalia	June + SeptemberNovember

Sudan MarchAugust

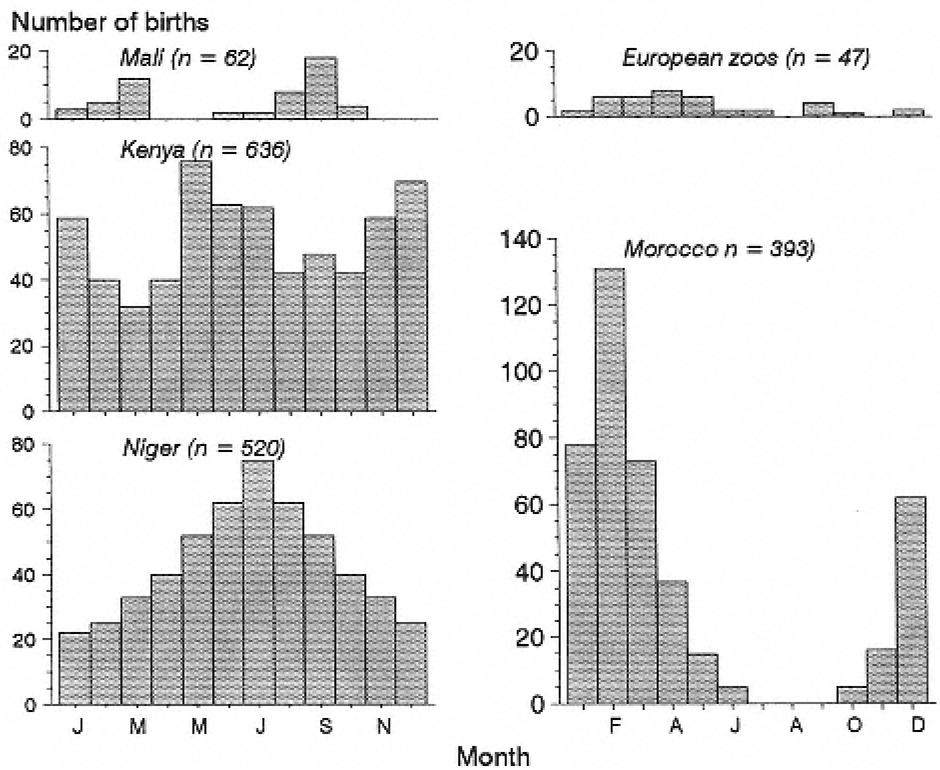


Fig. 11.8
Distribution of births in camels in different areas.
(Source: Wilson *et al*., 1990 (from various primary sources).)

being breeding all the year round, there are significant differences among months in the numbers of births with most taking place in May/June and November to January. A regression analysis on births and rainfall (as a proxy for primary productivity of vegetation) at each of 1215 months earlier did not show any correlation between rain and births.

In northern Niger there were also significant differences among months in the number of births but the pattern was more pronounced with a distinct peak in the short rainy season. The best correlations between assumed conception (12 months prior to parturition) and climatic variables were with minimum, average and maximum temperatures, and with daylength. Rainfall was again not significantly correlated with conception but it did improve the correlation when taken in conjunction with the minimum temperature. In Morocco 71% of 437 births in a 4-year study were in January to March.

Nutrition

The camel is owned mainly by groups that are prepared to be highly mobile and accompany their animals in the quest for feed and water. Its size and long legs, economy in the use and turnover of water, tolerance of high levels of salts in both feed and water, the peculiarities in its digestive system and digestive processes are adaptations to, and confer a comparative advantage over other domestic species in, the arid environments in which camels are usually found.

The Camelidae appear to be significantly more efficient in digesting dry matter, fibre, cellulose and crude protein than other domestic ruminants (although some wild ruminats may be as efficient as camels in some aspects of digestion) and domestic non-ruminants. This is probably due to the rapid and frequent cycling of the stomach contents.

The Digestive System.

All Camelidae have a thin upper lip, split in the middle, and prehensile for selecting and grasping feed. The upper dental pad is hard. The small tongue is very mobile and assists in feed selection. There are well-developed parotid, maxillary and molar salivary glands, smaller sublingual glands and very small glands associated with the cheek papillae. The oesophagus is of large capacity and also has secretory structures that assist the salivary glands in their functions.

The camelid stomach has only three compartments compared to the four in true ruminants (Fig. 11.9). The rumen and reticulum of ruminants have clear analogies in the camelids but these are better referred to as compartments C1 and C2 in the latter. The long tube-like C3 of the camelid performs similar functions to the omasum and the abomasum of true ruminants. The first compartment has cranial (or upper) and caudal (or lower) sacs while C2 has a ventricular groove which seems to function in a manner similar to that of the ruminant reticular groove.

The glandular sac areas of C1 comprise several small chambers separated by mucosal folds that are covered by columnar epithelium in the cranial part and by glands in the ventral part. These sacs, once considered to be the camel's water store, are now known to be secretion areas for enzymes as well as being zones of fermentation and sites for absorption of the end products of digestion. The non-glandular mucosal surfaces of both C1 and C2 are composed of unkeratinized and stratified squamous epithelium.

The intestines are similar to those of ruminants. The colon is large in diameter and is a major site of water absorption. The liver is markedly lobulated. The camel has no gall bladder.

Nutritional Physiology

Motility

Motility in the camel stomach differs from that of ruminants (Heller *et al*., 1986). In compartments C1 and C2 the cyclical pattern of motility consists of A and B contractions (Fig. 11.10). Each cycle starts with a strong contraction in the canal be-

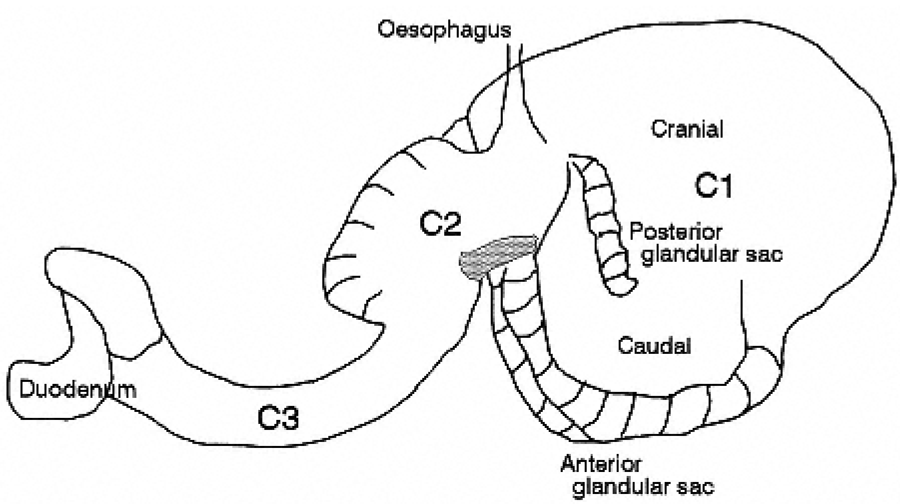


Fig. 11.9
Stomach morphology in the Camelidae.

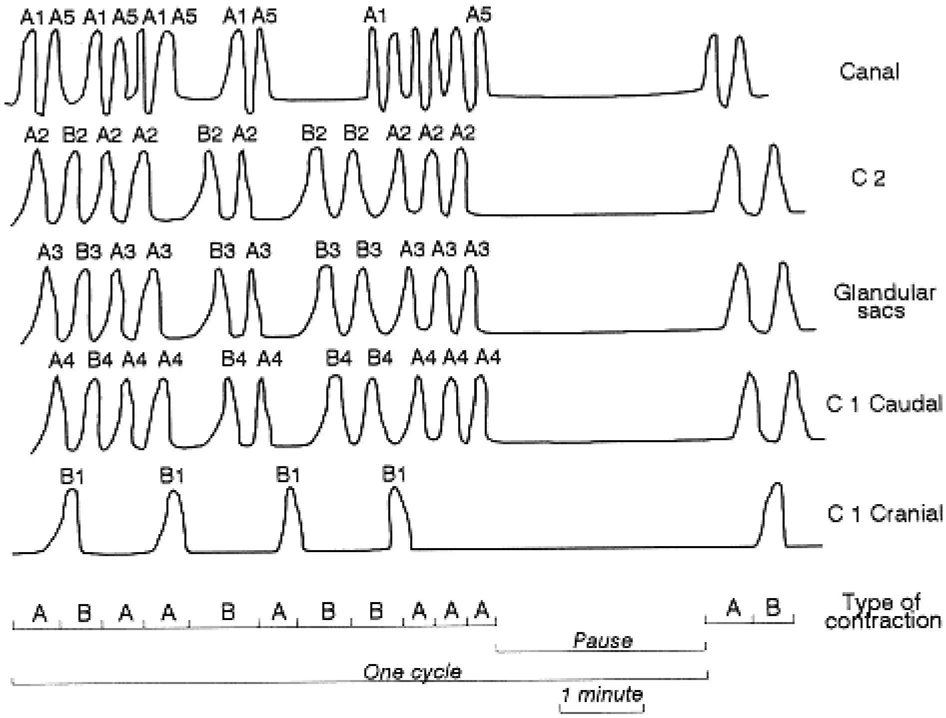


Fig. 11.10
Contraction patterns in the fore-stomach (compartments A and B) of the camel.
(Source: Heller *et al*., 1986.)

tween compartments C2 and C3. This is followed by a single rapid contraction in C2, followed by a short relaxed phase of the canal prior to a further contraction, during which stage C2 relaxes while the caudal portion of C1 contracts. The proximal part of the canal thus contracts before the distal part. A typical motility cycle includes seven A-type and five B-type contractions and lasts for about 34 minutes in camels, including the resting phase. In llama each cycle lasts only about 1.5 minutes. Filling of C2 with food decreases the number of contractions per cycle but increases the rate of cycling. Strong contractions that push food round C1 in an anticlockwise direction squeeze out fluid that is then absorbed in the glandular sac region. Contractions along the length of C3 occur continuously. It was originally thought that the movement was not peristaltic, at least in the llama, but it does appear that in the camel the movements are peristaltic.

Movement of Digesta

The contents of C1 and C2 pass to C3 when strong contraction in C2 causes an expansion of the connecting canal. Canal motility is therefore responsible for the flow of digesta from the fore-stomach to the lower part of the gastrointestinal tract. In llama, the flow rate is estimated at 850 ml/h equivalent to about 17 ml at each contraction. Particle size varies from 0.1 mm to 10.0 mm in C1 and C2. The maximum size of particles which can pass from this area to the lower parts of the alimentary tract is 35 mm in camels. Particle size tends to increase with increased dietary fibre content.

Retention Time

A limiting factor in the use of cellulose from cell wall constituents is the slow rate of microbial breakdown. Retention time of feed particles in the C1/C2 fermentation chamber is important as it largely governs the amount of fibre digested. Longer retention times are a prerequisite for efficient digestion of fibrous diets. In the fore-stomach of the one-humped camel small particles are retained for 41 hours while larger particles are retained on average for 57 hours. This is longer than in other camelids in which, for example, small particles are retained for 29 hours in the llama. Camels have longer retention times than true ruminants and can be expected to be more efficient in digesting fibre. Fluid is retained in the one-humped camel's fore-stomach for 14 hours, this being shorter than that of the llama and of true ruminants. High fluid turnover rates support rapid microbial fermentation through a higher buffering capacity and improve outflow of the soluble products of microbial metabolism.

Major factors that appear to be implicated in the selective retention of large particles in C1/C2 (so that they can undergo further breakdown) are an unequal distribution of particles and canal motility. Large particles that do pass into C3 are held up to ten times longer than small particles and fluid.

Rumination

Regurgitation of the food bolus occurs at maximum contraction of the upper part of C1. Eructation of the gaseous products of digestion and fermentation takes place at the same time as the contraction of the caudal part of C1 while the cranial portion is relaxed. Reduction of feed is achieved initially by chewing and rumination is therefore essential for efficient breakdown of particle size. Total chewing time might eventually become a limitation to further breakdown of particle size. Most rumination in camels that are herded by day takes place at night.

Rumen Chemistry

There is a high concentration of short-chain fatty acids in C1. Fermentation rates and pH are similar to those for cattle. Differences in stomach morphology between camelids and ruminants do not apparently influence the fermentation rate but, as noted, fluid and small particle outflow is faster. Ruminal protozoa differ in camels from those of sheep (Bhatia *et al*., 1986). *Entodinium* sp. account for 75% of all protozoa in camels and sheep when fully hydrated but drop to 68% in water-deprived sheep and increase to 84% in dehydrated camels. *Entodinium* is largely responsible for digestion of the starch fraction of the diet. *Epidinium, Metadinium* and *Eudiplodinium* account for the rest of the ciliate protozoa in camels, while *Diplodinium* forms the bulk of the non-*Entodinium* population in sheep. High levels of *Entodinium* and *Epidinium* in the fore-stomach of the camel indicate an ability for efficient digestion of the complex polysaccharides, the nitrogen materials and the lipid-containing chloroplasts of the ingested plant material.

Absorption rates of volatile fatty acids (VFA), sodium and chloride are two to three times faster in the camel fore-stomach than they are in goats and sheep. Farther back in the alimentary canal, other solutes and water are rapidly absorbed. About 60% of sodium, 70% of VFAs and 30% of water are absorbed in the fore-stomach. Acidification is high in the hind-stomach with high concentrations of chlorine.

Camels are well adapted to low protein diets but this is assisted to some extent by their ability to select high quality material. The recycling rate of urea increases under stress. Recycling efficiency of urea increases from 47 to 86% in camels in which dietary protein is reduced from 13.6 to 6.1%. Blood concentrations of urea do not apparently affect the amount of urea returned to the alimentary canal. It seems that the perme-ability of the stomach lining to urea changes with the type of diet fed. Most recycled urea is absorbed in the fore-stomach where both VFA and CO_2 levels influence permeability. High VFA concentrations increase the rate of absorption, butyric having a greater effect than either acetic or propionic acid.

Feed Preferences

The one-humped camel is a concentrate selector whose diet comprises mainly browse, being about 35% of leaves of leguminous and other trees and 65% of seeds, pods, flowers and twigs (Coppock *et al*., 1987). Selectivity is aided by the prehensile upper lip and mobile tongue. The camel has access to feed not available to other domestic species, even the goat, because of its height (Fig. 11.11). Camels are not, however, obligate browsers and graze grasses at lower levels if no or little other choice is available (Fig. 11.11). Browsing is, however, of considerable advantage to the camel itself (Coppock *et al*., 1987) in reducing competition for feed resources with other species (Table 11.7). The browsing habit also provides advantages to camel owners in allowing them to keep a greater total biomass of domestic herbivores on a unit area without normally contributing to greatly increased environmental degradation.

The feed preferences of the camel and its ability to select the most nutritious and digestible parts of plants ensure that it has a high quality diet throughout the year (Table 11.8). It is able to maintain a diet with a minimum crude protein content of 14% in the dry season in Kenya while cattle at this period are on a very low protein diet (Rutagwenda *et al*., 1990). In terms of cellulose content, which contributes to low digestibility, camels select a diet with the lowest value of this

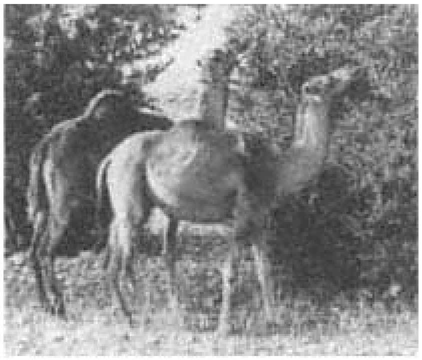


Fig. 11.11
Camels in Morocco browsing at a height
in excess of 3 m

Camels grazing in northern Tunisia.

Table 11.7 Forage class composition (% of dry weight) at different seasons for live species of livestock in south Turkana, Kenya.
(*Source*: adapted from Coppock *et al*., 1987.)

Animal species	Season	Forage class (% of diet) Grasses/herbs	Seeds/pods	Dwarf shrubs	Large shrubs/trees
Cattle	Wet	96	0	4	0
	Dry	99	0	+	+
Donkey	Wet	63	0	37	0
	Dry	78	+	22	+

Sheep	Wet	64	0	32	+
	Dry	73	9	18	+
Goat	Wet	21	0	37	42
	Dry	52	29	14	5
Camel	Wet	2	0	86	12
	Dry	5	0	49	46

Table 11.8 Crude protein and cellulose contents (% of dry matter) at three seasons for five domestic herbivores in Isiolo district, Kenya. (*Source*: Rutagwenda *et al*., 1990.)

Livestock species	Season and feed component (% of diet)					
	Dry		Intermediate		Green	
	Crude protein	Cellulose	Crude protein	Cellulose	Crude protein	Cellulose
Cattle	45	3740	68	3339	1012	3236
Donkey	58	3740	79	2832	1113	2430
Sheep	911	2029	1013	1720	1520	2125
Goat	1114	1522	1114	1618	1722	1622
Camel	1417	1422	1417	1316	1822	1417

feed component while cattle have the diet with the highest proportion. Camels have least dietary overlap with cattle, with a maximum of only 8.5% of plant species being eaten in common during the green period of the year and 3.3% in the dry season. Greatest competition for feed resources is found between camels and goats with 47.5% dietary overlap in the dry season and 12.4% in the green season. Sheep (30.5 and 14.2%) and donkeys (18.9 and 72%) are intermediate in dietary competition with camels.

Feeding Behaviour

In systems where camels are herded, feeding and travel activities are usually confined to the 1215 hours of daylight. Their ability to go long periods without water releases them from lengthy travel times and effectively frees time for feeding and resting. In some areas camels spend more time resting on watering days than they do on other days, because of the long time they spend waiting at wells or other sources. Camels in Kenya spend up to 8 hours per day actively feeding and travel 1518 km in search of their nutritional needs (Coppock *et al*., 1988). On watering days camels travel as much as 24 km. Relatively little time is spent resting in the diurnal period whilst out at pasture (Fig. 11.12) but if time in the night enclosure is included the proportions of time spent feeding, resting and travelling change from 69, 9 and 22% for day only to 35, 55 and 10% for day plus night. Donkeys most closely resemble camels in feeding time but travel much shorter distances (about 8 km on non-watering and 18 km on watering days). Cattle spend less time feeding and more time travelling than all other species, with goats and sheep combined being intermediate between the extremes.

The ability to select preferred feed allows camels to maintain a high proportion of green material in the diet all year. In south Turkana all domestic species were able to consume 100% of green matter during the wet season. In the dry season only camels (75%) were able to select more than 50% of green material with cattle and donkeys, being mainly herbaceous grazers, achieving less than 20%. More than 70%, and as much as 95%, of the feed selected by camels is dicotyledons. Major plant groups eaten include the Leguminosae (*Acacia* species such as *tortilis, nilotica* and *mellifera; Indigofera*), Burseraceae (*Commiphora*), Capparaceae (*Boscia; Maerua; Cadaba*), Rhamnaceae (*Ziziphus*), Simaroubaceae (*Balanites*) and Salvadoraceae (*Salvadora; Dobera*). In other areas the so-called camel thorn *Alagi maurorum* is a major constituent of the diet as are many salty plants such as *Haloxylon recurvum, Salsola, Suada* and *Atriplex*. Access to these plants considerably reduces the need to feed salt or to take animals on a 'salt cure'. In the Mediterranean area the low-growing herb, *Artemesia herbaalba*, is a main feed. Among grasses, *Aristida* species contribute to camel diets and in the very dry areas of Northern Africa the tussock forming perennial, *Panicum turgidum*, is often a large proportion of total intake.

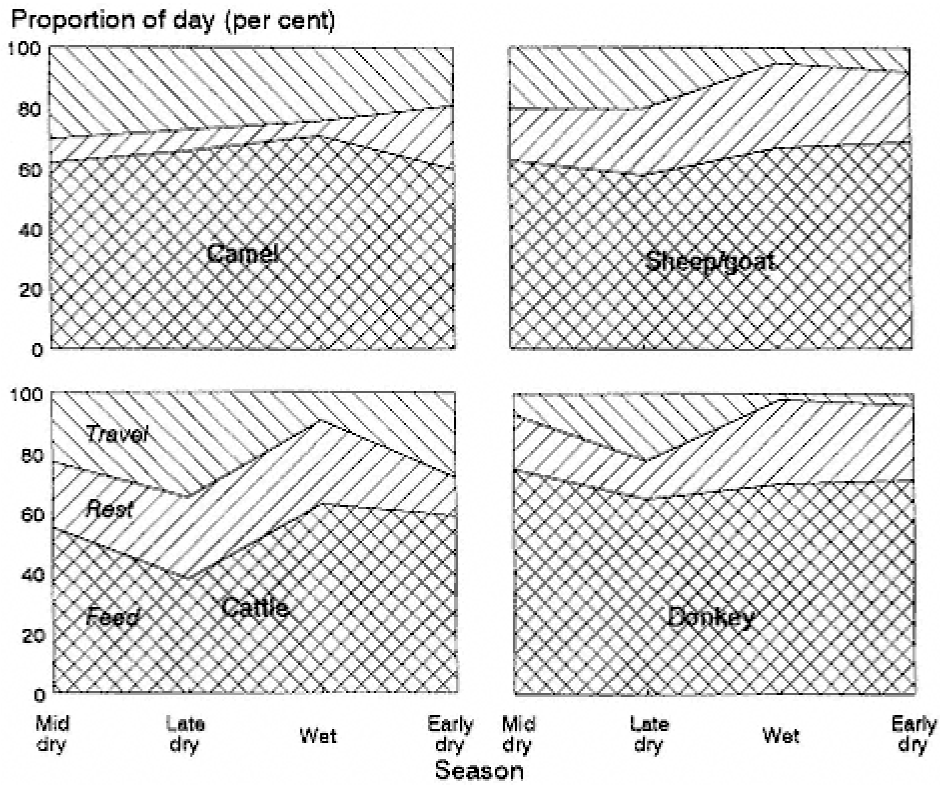


Fig. 11.12
Day time activity patterns of domestic livestock at various seasons in south Turkana, Kenya.
(Source: Coppock *et al*., 1988.)

In addition to being taken on migration for the salt cure, it is usual for camels on the southern edge of the Sahara and in parts of the Maghreb countries to migrate on occasions to the 'gizu' and 'acheb'. These vegetative formations grow only in years that have particular combinations of temperature and rainfall. Among the plants found, all of which are low growing, are species of *Indigofera, Morettia philaeana, Neurada procumbens, Aristida papposa*, and several *Cyperus* species (Wilson, 1978b).

Intake.

There is still relatively little known about the amounts of feed eaten by camels, especially under free-ranging conditions. Published results are conflicting (Gauthier-Pilters & Dagg, 1981) but it appears that intakes per unit body weight are low compared to other domestic species. This may be because of the larger body size and lower energy requirements. Growing camels of 1 year of age in Tunisia had an intake of 1.6 kg DM (dry matter)/100 kg per LW (liveweight) and on this gained 326525 g/day at a conversion ratio of 7.4 kg DM per kg of gain (Kamoun & Wilson, 1994). Studies in Egypt have indicated an intake of about 4 kg DM per head per day to give a gain of 214238 g/day.

Digestibility

Coefficients of digestibility for the major nutritional components are often higher in camels than they are in the domestic ruminants. This is mainly because camels adapt to poor quality forage if they have no alternative sources of feed, in particular by increasing retention time. The major strategy in relation to diet quality, however, is to select green parts of plants with high protein and low cellulose. This strategy is aided by low energy use, high salivary flow and high levels of ammonium for microbial synthesis.

Health

The unfavourable environment in which camels are reared is to some extent inimical to disease organisms. Extensive management should be a further factor in reducing the risk or severity of disease. In spite of a general reputation for hardiness and resistance, which appears to be true in relation to adult camels in which the annual death rate may be as low as 25%, morbidity can be high. This is especially so in the very young camel where the death rate is also commonly 30% up to 1 year but may be as high as 50%.

Passive immunity to many diseases is not transmitted to young camels via the epitheliochorial placenta and therefore has to be acquired after birth. Colostrum carries many of the antibodies to disease and would be capable of transferring resistance to the newborn camel. In many camel societies, however, the colostrum is withheld from the young. This is undoubtedly a contributing factor in the high morbidity and high mortality rates suffered by camels before weaning. Early embryonic death and occasional outbreaks of abortion contribute further to overall mortality, poor real reproductive performance and slow herd expansion rates.

The literature on the diseases of the camel is the most numerous of all research papers on the animal and there are several recent books on the subject (Higgins, 1986; Gahlot & Chouhan, 1992; Wernery & Kaaden, 1995). Camels seem to be carriers of, are susceptible to, or suffer from, a vast array of infectious and parasitic diseases.

Infectious Diseases

Organisms of many diseases have been searched for, and found, in the one-humped camel. The presence of antibodies to foot-and-mouth disease, for example, in 70% of camles in Egypt, is not associated with a clinical expression of that disease and, indeed, it is not known if the camel acts as a reservoir of infection or is able to transmit it to other species. The presence of antibodies to other disease organisms, important in other domestic animals but about which similarly little is known of the role of the camel, includes African horse sickness, *Anaplasma*, *Brucella*, *Toxoplasma*, *Coxiella* (Q-fever), blue tongue, influenza, parainfulenza, Rift Valley fever and *Pasteurella*. These antibodies are present over wide areas and in varying proportions of animals. An important viral disease, which is widespread in Kenya and the Persian Gulf and which causes considerable economic loss but which can be treated by a vaccine, is camel pox. Contagious ecthyma or pustular dermatitis, which produces lesions similar to those of pox, is also widespread.

Trypanosomosis, usually caused by *Trypanosoma evansi*, is a major clinical disease and probably the single most important cause of health-related economic loss in camels (Touratier, 1993). Unlike other trypanosome species, *T. evansi* does not have to undergo part of its life cycle in tsetse flies and it is transmitted mechanically by biting flies. These flies are usually of the tabanid group, mainly of the genus *Tabanus*, although the principal ones in Somalia are *Philoliche zonata* and *P. magretti*; stable flies of the genus *Stomoxys* are also carriers of the disease in some areas. Many older tests for detecting trypanosomosis, including mercuric chloride, are still used but modern and rapid techniques are increasingly being employed and include complement fixation and card agglutination tests as well as enzyme-linked immunosorbent assay (ELISA) and radioimmunoassay (RIA). Chemoprophylaxis and chemotherapy have varying success in combatting and controlling the disease.

Parasitic Diseases

A wide range of parasitic diseases is found in camels, including internal and external parasites. Few deaths seem to be attributed directly to parasites but they are undoubtedly a major cause of economic loss. Helminths are the most common internal parasites. Some, such as *Haemonchus contortus*, are common in many animals while others, including *H. longistipes*, *Camelostrongylus mentulatus* and *Globidium cameli* are virtually restricted to camels. *Trichuris*, *Impalaia*, *Trichostrongylus*, *Cooperia* and *Oesophagostomum* are other important roundworms, and coccidiosis (*Eimeria* spp, especially *E. cameli* and *E. dromedarii*) is an important debilitating disease of young camels.

The camel is a principal intermediate host of the zoonotic hydatidosis. Cysts of *Echinococcus granulosus* are found in camels over a very wide area. Prevalence rates are usually higher in camels than in other domestic animals, as is the proportion of viable cysts. The nomadic life style, with a failure to dispose hygienically of the waste products of human metabolism and living in intimate association with dogs, is probably a major aetiological factor in the mandogcamel cycle of the disease.

Among the external parasites the larvae of the nasal bot fly, *Cephalopina titillator*, are widespread and almost universally present in camel sinuses. Ticks have not been shown to be responsible for actual transmission of disease to camels but cause physical irritation and the wounds they cause may allow the entry of other disease organisms. The economically most important external parasite, however, is the one that causes sarcoptic mange, *Sarcoptes scabiei*, which is usually accorded a separate variety status, *cameli*. Nomads in the Sudan use a traditional remedy made from *Acacia* bark against mange. A more usual, and probably more effective, treatment is with the modern wide-spectrum drug ivermectin. This chemical is also effective in combatting the nasal bot fly and most internal parasites.

Management

Most camels are kept by traditional owners in very extensive low input and relatively low output systems. Some form of migration, transhumance or nomadism is usually a basic feature of this type of production. Very small numbers of camels are managed under experimental conditions (and these numbers at a single site often appear to be too small for the firm conclusions drawn from the usually short duration experiments to be justified). Even fewer camels are kept under truly commercial conditions.

It is usual to say that no management is practised in the traditional migratory systems although migration itself is a sophisticated ecological adaptation and management response to the rigours of a harsh environment. In addition to the skilful use of long distance movement to ensure the best nutritional conditions (which also includes mineral status) for the animals, frequent local movements of the camping unit in relation to water and feed sources also contribute to management. Some other aspects of management include splitting of herds to reduce risk (although social and cultural factors are also important in herd dispersal strategies), manipulation of the herd sex and age structure to ensure the best mix for the required production objectives, and adjusting the overall size of the herd especially in relation to the labour available to control it.

Herd Composition

Camel systems have not been exempt from the criticism that is often expressed of traditional producers that herds are not managed efficiently in terms of sex and age structure. The premise is that there are many unproductive females in the herds and that the case is even more extreme for males with many of these being in excess of those needed to provide an adequate breeding ratio. This conventional wisdom, as for other species, is wrong as it usually fails to take account of the production objectives. These objectives are often multiple and complex and result in a herd composition which is a compromise between the ideal and the practical and that is also influenced by performance and climate. Herd composition can also be used to confirm other sources of information on herd function, reproductive performance and climatic events. The rather limited data on this aspect of camel productivity (Table 11.9) tend to confirm that the slow rate of reproduction and the long generation interval are major determinants of herd composition.

Table 11.9 Composition by age and sex of camel herds in various production systems. (*Source*: Wilson *et al*., 1990 (from various other sources).)

Sex and age	Production system					
	Rendille, Kenya	Laayoune, Morocco	East-central Niger	North Niger	Butana, Sudan	Central-south Somaliaa
Male						
>4 years	5.2	22.4	21.8	17.1	22.0	1.0
14 years	13.9	13.6	8.1	12.3	9.8	
<1 year		7.1	7.2	8.2	4.8	9.0
Castrate	12.0	n.a.	n.a.	4.8	n.a.	8.0
Total	31.1	43.1	37.1	40.4	38.6	18.0
Female						
>4 years	55.0	28.2	42.7	38.9	41.4	71.0
14 years	13.9	13.1	10.7	15.6	14.2	
<1 year		13.6	9.4	5.1	7.8	11.0
Total	63.9	54.9	62.8	59.6	63.4	82.0

n.a. = not available.
a 'Young' animals <2 years, all other classes ³2 years.

Identification

Camels may often be owned primarily by the clan or tribal group and only secondarily by the individual or family. This arises from the degree of interdependence that is required, and has developed, to sustain life in the harsh desert environment. Clan or tribal brands are therefore extremely important in establishing ownership and are known and respected over a distance of perhaps hundreds of kilometres. Brands contribute in normal times to prevention of theft and, where sales take place, they are often witnessed (and ownership title verified) by an arbitrator who is an acknowledged expert on brand marks and who guarantees to both seller and buyer the legitimacy of the transaction. Individual brands may also serve to establish ownership. More important for the owner himself, however, is intimate knowledge of his animals and their ancestry and present relationships in the herd which often ensures that there is no real need for any external or immediately visible system of marking.

Dentition and Age

The dentition of camels can be used, as for other species, to assist in the determination of age. The dental formula differs from that of true ruminants by the presence of incisors in the upper jaw and of canines, or tushes as they are sometimes known, in both upper and lower jaws. The formulae for the dentition of camels in both the deciduous and permanent phases are:

Deciduous teeth:

$$\left(I\frac{1}{3}\quad C\frac{1}{1}\quad P\frac{2\text{–}3}{1\text{–}2}\right)\ 2 = 20\text{–}22$$

Permanent teeth:

$$\left(I\frac{1}{3}\quad C\frac{1}{1}\quad P\frac{1\text{–}2}{1\text{–}2}\quad M\frac{3}{3}\right)\ 2 = 30\text{–}32$$

Estimation of the age of camels from their dentition is perfectly possible (Table 11.10) but does require some experience and skill. This is

Table 11.10 Age-related dentition of the camel. (*Source*: adapted from Rabagliati, 1924.)

Jaw and teeth	Age: Temporary or deciduous teeth: Birth	1 week	2 weeks	1 month	3 months	6 months
Upper jaw						
Incisors, corner					just	up
Canines					small	up
Premolars 1	gum	just	through	up	up	up
Premolars 2	gum	just	through	up	up	up
Premolars 3	gum	gum	gum	through	up	up
Lower jaw						
Incisors, central	gum	just	through	up	sharp	in-wear
Incisors, lateral	gum	gum	just	through	overlap	in-wear
Incisors, corner	gum	gum	gum	just	overlap	in-wear
Canines					incisor-like	up
Premolars 1	gum	just	through	up	up	up
Premolars 2	gum	gum	gum	through	up	up

Jaw and teeth	Permanent teeth: 1215 mo	2.5 yr	3.0 yr	4.5 yr	5.0 yr	5.5 yr	6.0 yr	6.5 yr	7.0 yr
Upper jaw									
Incisors, corner							through	up	up
Canines							through	up	large
Premolars 1								through	dark
Premolars 2					gum/just	through	up	up	wear
Premolars 3					gum/just	through	up	up	wear
Molars 1	through	up	up	up	wear	wear	wear	wear	wear
Molars 2		just	through	up	wear	wear	wear	wear	wear
Molars 3					gum	through	up	up	wear
Lower jaw									
Incisors, central				just	through	up	wear	wear	worn
Incisors, lateral						gum	up	wear	wearing
Incisors, corner								through	up
Canines							through	up	large

Premolars 1								through	dark
Premolars 2					just	through	up	up	wear
Molars 1	through	up	up	up	wear	wear	wear	wear	wear
Molars 2		just	through	up	wear	wear	wear	wear	wear
Molars 3					gum	through	up	up	wear

because it is sometimes difficult to distinguish clearly between the deciduous and permanent incisors as there are no marked differences in the sizes of these two stages as there are in true ruminants.

Production and Productivity.

Camels have generally been considered principally as riding and pack animals but they have

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lost much ground in these roles and been taken over by modern developments. More recently it has been recognized that they have other important functions as part of the life-support system in arid areas and especially in their contribution to human nutrition through milk production.

Growth and Weight for Age

Mature camels weigh from less than 400 kg to more than 800 kg. Afar camels in eastern Ethiopia are among the lightest while Mudugh camels in southern Somalia are among the heaviest (Wilson, 1984).

Birth weights vary among breeds from 27 to 42 kg. Estimates of the heritability of birth weights are in the range of 0.32 to 0.57, the former being similar to estimates for many other species while the latter seems very high. Weights at different ages include estimates of about 100 kg at 3 months, 160 kg at 6 months, up to 280 kg at 12 months and 340 kg at 30 months.

Daily weight gains of young are from 300 g to more than 1000 g for animals to 1 year old. Nutrition and management interventions are more effective in promoting gain when applied early in life. Intake rates in relation to gain have been reported as 47 kg per kg or, expressed differently, as 2229 MJ ME (metabolizable energy) per kg gain to 120 kg at 120 days. Calves in Israel gained 870 g/d in very early life at a metabolizable energy intake of 19.45 MJ/d (Degen *et al*., 1987) with an average daily gain to 180 days of 680 g. Animals 1 year old in Tunisia fed 175 days on oat hay *ad libitum* and a concentrate of wheat bran and olive pulp gained 326565 g/d, consuming 1.6 kg DM/100 kg LW or 61 g DM/kg0.75 per day at a conversion ratio of 7.4 (Kamoun *et al*., 1989). The cost in weight of restricted water availability has rarely been studied; in India, 12 to 14-month-old camels averaging about 200 kg gained 430 g/d over 6 months on daily watering but only 380 g/d when watered weekly, while maintaining similar dry matter intakes (NRCC, 1990).

The problems associated with weighing camels are considerable, particularly in traditional herds. These need to be overcome if good data are to be obtained and used in the correct understanding of the factors affecting productivity. Measures that approximate weight, such as body condition score (Abdel-Rahim & El-Nazier, 1993) and linear measurements (Wilson, 1978a) must be used where necessary and appropriate.

Milk

Many traditional owners keep camels solely or mainly for milk. A major advantage of the camel as a milk animal in traditional systems is its ability to maintain production over a long period especially through the dry season when perhaps the only other domestic animal providing very small amounts of milk is the goat. Probably as a result of the continual drift of nomads to urban centres, informal camel dairies have developed on the perimeters of many large towns, including Djibouti (Fig. 11.13) and Nouakchott in Mauritania where 50 000 camels were each estimated to yield 68 litres per day in 1988. Commercial dairying has a long history in some areas such as Karachi in Pakistan but is a new development in some areas, especially in Saudi Arabia and Libya.

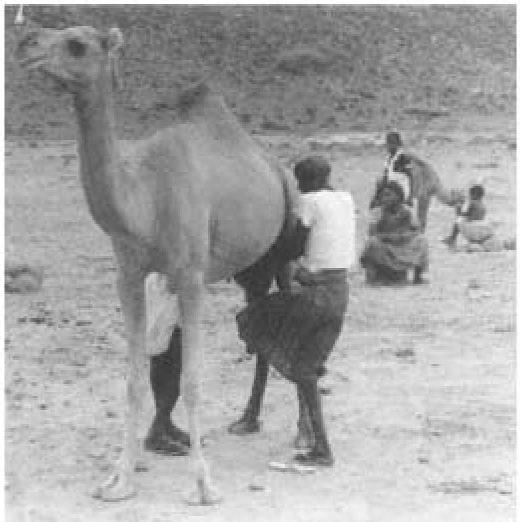

Fig. 11.13
An Afar milking a camel in the periurban dairy belt of Djibouti.

Composition

Camel milk is usually bluish-white in colour and has a slightly salty taste. In normal situations total solids are in the region of 1114% and fat in the region of 34%. Mineral contents vary according to the content of the feed but camel milk is a good source of vitamin C. The first colostrum is very low in fat (0.23%) but the fat level becomes normal at about 10 days. There are changes in other constituents over the same period: protein changes from 13.0 to 4.0%, lactose from 2.7 to 5.1%, and total solids from 20.5 to 14.7%.

Yield

Data on milk yields indicate that the production potential of camels varies over wide ranges in terms of total yield and lactation length. The highest yields are probably achieved only at the cost of very high quality and expensive feed. This negates the comparative advantage of the camel and it may be considered that if quality feed is available it would best be used by dairy cows already bred for this production function.

In one study in Pakistan it was claimed that camels outyielded Friesian × Sahiwal and Sahiwal cattle as well as buffaloes and that these higher yields compensated for lower fat contents such that camels produced more total fat. It seems likely that traditional owners, however, will want to continue to breed camels with lactation persistencies of up to 18 or more months and not want to lose this characteristic in exchange for high daily yields. In Ethiopia owners were happy with a milk offtake for human consumption over that suckled by the calf of 1045 litres in 430 days or about 2.2 litres per camel per day.

Products

For many years it was considered that the composition of camel milk, perhaps related to fat globule size and distribution, made it difficult or impossible to convert liquid milk to butter. There were similar problems with converting milk to cheese. Recent advances in the understanding of the chemistry and biochemistry of camel milk and in the technology of processing have shown that it is possible to make both butter and cheese without too much difficulty (Ramet, 1982, 1993). Other products of lesser interest that have been made from camel milk are a variety of yoghurts and soured milks, and ice cream.

Transport and Draught

The contribution of camels to urban and rural energy needs in the areas they are found in is still considerable. Mechanical transport has taken over some of their former functions but camels would never have been able to fulfil all the transport demands of modern economies. In addition to household needs, such as the transport of water and of nomad houses, camels still provide commercial transport of salt in Niger and Ethiopia and many other examples could be cited. In Pakistan and India camels in carts transport many urban goods and do this, where small quantities are delivered to individual service points and halts there are relatively long, more economically than motorized vehicles.

The role of camels as draught animals and sources of primary power has almost certainly increased as nomads have settled and become cultivators or have realized the economic potential of their animals in agro-pastoral areas. Use as a personal riding animal has probably diminished in importance, especially over longer distances.

Camels are used widely as plough animals and seem to be equally as efficient in producing draught as most other species occupied in this role. Where camels have replaced or work in parallel with traditional draught animals the harness and yoke systems are often the same or similar to the ones used for these other species. These have, however, often proved to be inefficient in transmitting power and cause discomfort and injury to camels. Some attempts to adapt the traditional draught harness to camels have had some success (Fig. 11.14) but if camels are to prove truly efficient sources of power, much more work is needed to develop appropriate equipment.

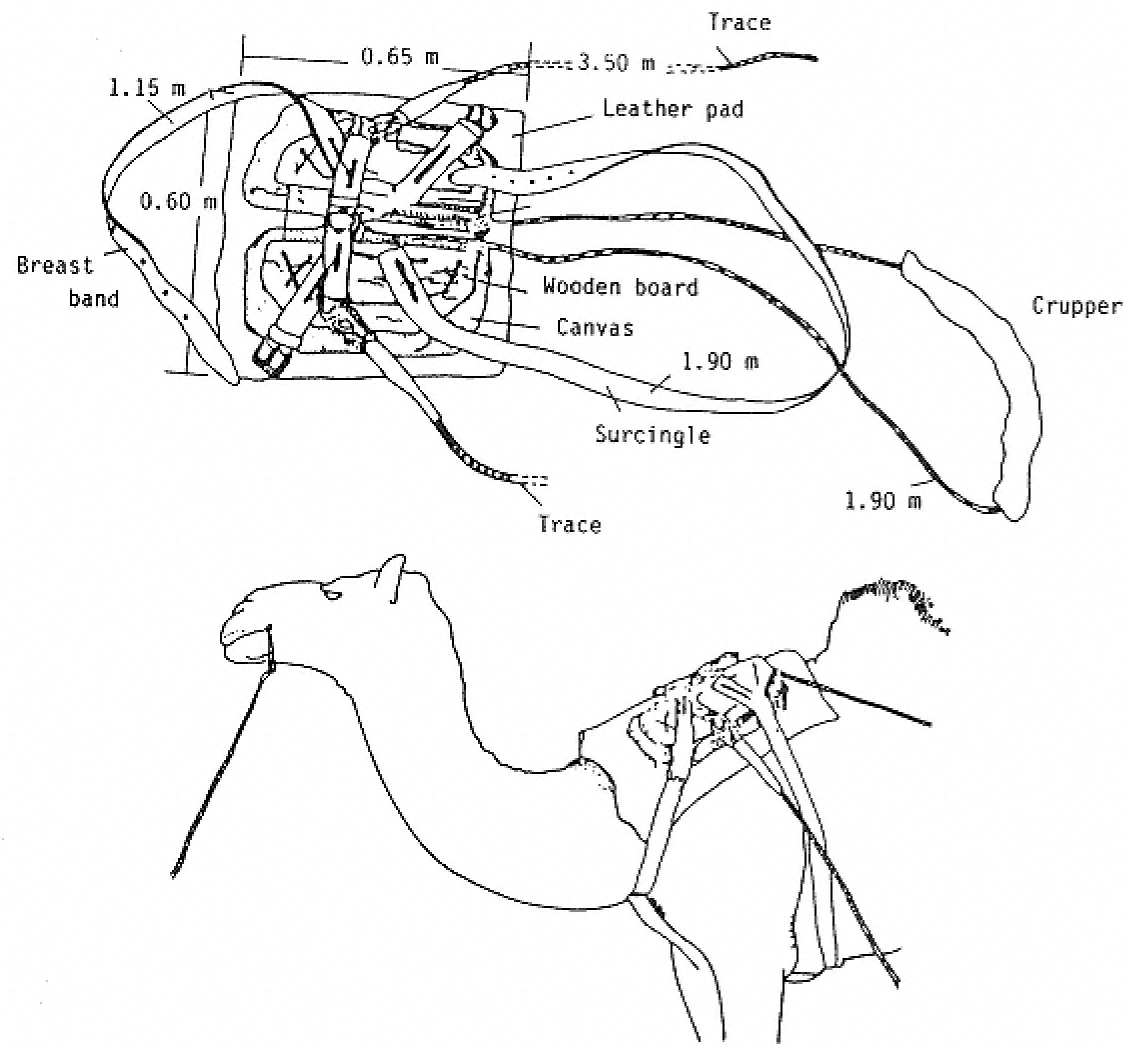

Fig. 11.14
Camel draught saddle adapted from an Ethiopian ox model.
(Source: Dénis Gerard, pers. comm., 1990.)

Meat

Milk and draught (in its wider sense) are the principal products of the camel. Meat, with very few exceptions, is very much a by-product of a camel system and comes mainly from old males and females which have passed a useful life in other functions. Even though camel meat is usually from old animals it often commands a specialized market. In terms of acceptability it has been scored as high as or better than beef by taste panels in the Arab states. Camel meat is usually only a small proportion of the meat consumed in a country but in Saudi Arabia meat from camels is equivalent to about 50% of nationally produced red meat. Camel meat has also been made into sausages, in which form it has similar cooking and taste qualities to those made from beef.

Dressing percentages of camels are in the range of 45 to 55% and exceptionally up to 60%. Total carcase composition is about 66% muscle, 19% bone and 14% fat with the fat being mainly from the hump. Lean meat has more moisture and less fat than beef, the main constituents of muscle being 75.5% water, 21.4% protein and 1.4% fat. The pH is about 5.75.

Hair

Fibre is a minor product of the one-humped camel but is more important as a speciality fibre from the Bactrian camel. Small quantities of hair are harvested from camels in Sudan, Niger, Mauritania and the countries of North Africa. The Turkman one-humped camel in the south of the former USSR produces about 2.52.7 kg fibre per year (males 3.3 kg, females 2.1 kg) with a diameter of 1227 µm and a length of 412 cm.

Constraints to Increased Productivity and Opportunities for Development.

Early formal research on camels was mainly limited to their origins and domestication and, to a lesser extent, diseases. The economic cost of trypanosomosis is reflected in the number of published articles that appeared during 191140. Other research areas attracted little interest until the 1950s. Major production aspects such as milk did not receive attention until the 1950s and even by 1980 references to these subjects were few. Husbandry and management were sadly neglected and practically nothing was known by 1980 of nutritional standards. Health and veterinary matters retained their prominent place throughout much of a middle period of research activity. Reproduction and anatomy were also popular but the latter overtook the former mainly, it would appear, because anatomical research can be carried out very cheaply, on one or only a few animals, and in the relative comfort of a slaughterhouse or a laboratory. Reproductive studies also continued, for the same reason, but were mainly confined to small numbers of animals or with specimens obtained from abattoirs. Research on the improvement of productivity and on increasing the effectiveness of management has, regrettably, continued to receive little attention. Nutritional research has been mainly confined to physiological aspects and there is still relatively little information on what camels actually eat, and its value to them, in their own environment.

There was much multilateral and bilateral support for camels in the 1980s and 1990s. National inputs in some countries have also increased. Investments in human resource and infrastructure development have resulted in well-qualified staff and laboratories with sufficient resources to manage the research that is needed to improve camel production. Support has also been provided for publication and information exchange. Co-ordinated research programmes, with a common theme and several countries participating, are popular among donors and recipients alike. The approach of many multilateral agencies, of improving national capabilities and concurrently facilitating exchange of information (and thus encouraging the majority of scientists to work in their own institutions) has served the research needs of the Camelidae better than the establishment of one or two centralized international centres would have done. Problems remain in making knowledge more widely available and transferring it to practical use. Mobilization of extension agencies has been slow for several reasons. One is that most scientists, by the nature of their background and training, are ignorant of the hopes and aspirations of the livestock owner and do not appreciate the need to provide a solution within his or her socioeconomic framework. Another is that scientists are cautious of involvement in field projects because they are extremely difficult to execute and control and are long term.

It is clearly necessary that a development programme have a research component to monitor the effects of innovations but equally desirable that scientists design research relevant to development programmes. Donor agencies and networks sponsored by them should promote and, if necessary, make support contingent on such interaction. The stated goals of many funding agencies are to generate and support research which will help owners to utilize their animals more efficiently and to improve the quality of life. Developing research infrastructure and providing scientists with a role in development are important intermediary steps. Increased interest in camelid research can only be considered encouraging. Much research, however, is of academic interest only and in the economic climate of the late twentieth century is wasteful of finite resources. Limited research funds might be better directed to studies of management and production in the real-life situation and to using what is feasible and best in systems where camels are the, or a, principal domestic animal. Support for future research should then be contingent on the transfer of knowledge, not only via publication in readily available sources (to satisfy the intellectual and career aspirations of scientists), but also by close collaboration of research institutes, extension services and development workers. Funding agencies should strive for more co-ordination of the support provided. In spite of the research undertaken and of some bilateral collaboration there has been little real attempt at fully co-ordinated, multilateral and interdisciplinary work. Regular critical reviews of research (international journal publication is one aspect of this as are peer reviews through regular meetings) and of development are required. A structured approach that ensures that research is relevant to local problems would include:

- Determination of current production levels and constraints by means of retrospective and longitudinal field case studies.

- Design of experiments and methodologies for overcoming the constraints by using local resources and simple interventions including strategic feed supplementation, changes in management and disease control.

- Testing solutions under actual operating conditions.

It is desirable that future research build on the outstanding abilities of the Camelidae to survive and produce in harsh environments and on for-ages not palatable to, and indigestible by, conventional stock. There should be no attempts to convert the camel to the equivalent of a high-yielding dairy cow, ill-adapted to its environment, destroying the natural resources on which it depends, and finally making beggars of its owners.

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12
New World Camelidae

Introduction

The New World Camelidae played a major role in the economy of Andean countries before the Spanish conquest. It is estimated that there were at least 10 million alpaca and somewhat fewer llama and that they were domesticated between 7000 and 6000 BP. The numbers of wild guanaco and vicuña are unknown but until the middle of the twentieth century they had been excessively hunted with the result that both were threatened with extinction. Fortunately considerable interest in all the New World Camelidae and recent research has provided valuable, but by no means complete, information on important aspects of their anatomy, digestive and reproductive physiology and diseases.

Origins and Ancestry

The domesticated New World or South American camelidsalso sometimes known as llamoidsand the guinea pig were the only domestic stock in the Andes in pre-Columbian times before the Spanish conquest. As with Old World camels, the New World ones belong to the subfamily Camelinae of the family Camelidae in the suborder Tylopoda of the order Artiodactyla.

There are four species of New World Camelidae of which two are domesticated and two wild. The llama, *Lama glama* (Fig. 12.1), is used mainly as a pack animal whereas the alpaca, *L. pacos*, is primarily a producer of high-quality fibre (Fig. 12.2). The two wild species are the guanaco, *L. guanicoe*, and the vicuña, *L. vicugna*. Although it is by no means certain the smaller alpaca probably derives from the wild vicuña (sometimes placed in a distinct genus *Vicugna*) while the larger and heavier llama is thought to be descended from the larger wild guanaco. All south American camelid species cross freely and all offspring are fully fertile. There is thus a case for treating the four species as a single one and giving those currently recognized subspecific status. All the South American camelids have a very similar karyotype with the same number of chromosomes ($2n = 74$), which is also the same as in Old World camels.

Domestication

There is more direct evidence of domestication of the South American camelids than there is of those in the Old World. The archaeological evidence suggests that the llama and the alpaca were domesticated at the very high altitudes of 40004900 m in the Andes of southern Peru and western Bolivia. An approximate time of first domestication, which resulted from a succession of generalized to specialized hunting to semi-controlled hunting and herding, would be about 6000 BP (before present). This estimate of the period of domestication has been based on changes in the type of molar teeth and in the increasing numbers of bones of young, as compared to old, animals found at archaeological sites.

Fig. 12.1
A group of female and young llama, *Lama glama*,
near Quito, Ecuador.

Fig. 12.2
Breeding females and young alpaca, *Lama pacos*,
at 4100 m at La Raya, Peru.

Numbers and Distribution

The llama, alpaca and vicuña are adapted to living in arid zones with low humidity, at high altitudes where the average annual temperature is in the region of 06°C (although minima of18°C are not unusual and day temperatures can rise to 20°C). Their principal habitat is the altiplano or 'puna' ecosystem of the central Andes at altitudes of 35004800 m. They also occur to the north in the 'paramo' or highland agro-ecosystem in Ecuador (Hervas Ordoñez, 1994). Precipitation in the wet 'puna' rises to 600 mm or more per year and in the dry 'puna' is 250420 mm; snow and hail, as well as rain, contribute to total precipitation, most of which falls in a 4-month season from December to March (Fig. 12.3).

The guanaco is found in more diverse habitats than the other three species. It ranges from sea level to 4500 m in hot and cold and in arid and humid zones but the largest populations are in the pampas or cold steppe towards the southern part of the continent in Argentina and Chile.

South American camelids are naturally distributed from north of the equator in Ecuador to about 55°S on Navarino Island in Chile at altitudes from sea level to more than 5000 m. The guanaco has the widest distribution of the four species. The vicuña has the most restricted geographical and altitudinal distribution and is usually found above 4000 m. Domestic llamas and alpacas are very important in the economy of the people of the Andean regions of Peru and Bolivia in which more than 90% of South American llamas and alpacas are found. They are of less importance in Chile, Ecuador and Argentina. In Ecuador their contribution to household incomes of poor peasant families is out of all proportion to their numbers (Hess, 1990). They are the best means of using the extensive highland resources since neither crops nor sheep or cattle can be raised profitably due to the problems imposed by the high altitude. Most alpacas and llamas are now raised at altitudes of 30005000 m but they were widely distributed among the coastal regions and the highlands during the Inca period. With the arrival of Europeanswho totally neglected the Camelidaeand the introduction of sheep and cattle, camelids were confined to marginal areas where the newly introduced species were unable to survive. In a strange twist of destiny other countries, including the United States, Great Britain, New Zealand and Australia are rearing increasing numbers of llamas and alpacas in the drive to diversify their agricultural production (Russel, 1994).

There are estimated to be somewhat under 8 million New World camelids in South America (Table 12.1). The domesticated species are by far the most numerous. Peru has about 90% of all alpacas, 25% of all llamas, 75% of all vicuñas and about 55% of all the *Lama* species. Bolivia has most llamas (70%) and about 10% of alpacas. Chile has relatively small populations of the do-

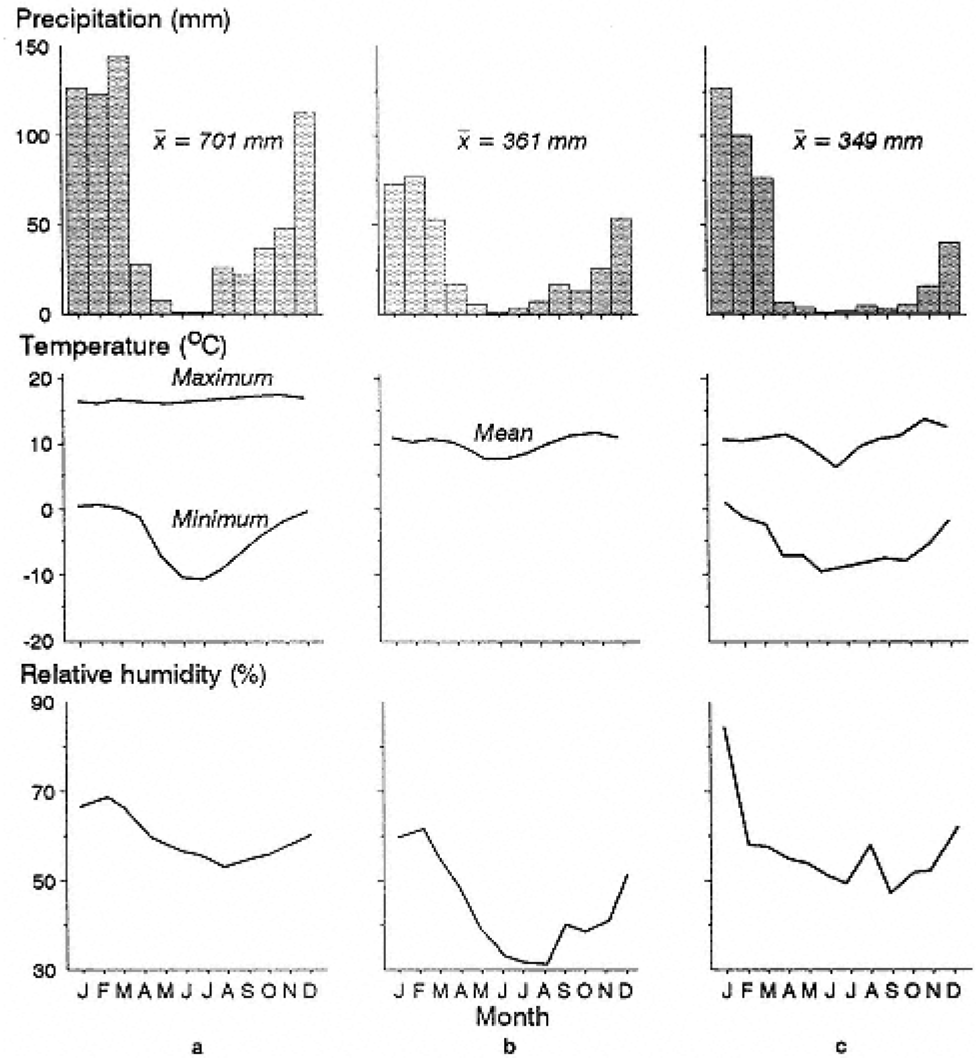

Fig. 12.3
Climatic normals at typical sites of South American camelid production. (a) Chuquibambilla, Peru/14°48'S/70°44'W/3910 m; (b) Condoriri, Bolivia/17°32'S/67°14'W/3830 m; (c) Lauca, Chile /18°10'S/69°27'W/4470 m).

mestic llama and alpaca but larger relative ones of the vicuña and guanaco. Argentina has only a very small percentage of the domestic species, no vicuñas but more than 95% of guanacos. There are a very few guanacos in Paraguay.

The domestic species have steadily increased in numbers over recent years. The importance of conserving and increasing the numbers of the wild species is not only on aesthetic grounds but also because they may be useful in maintaining diversity in the future and in widening the gene pool of the llama and alpaca (Novoa & Wilson, 1993). There is considerable evidence that both the vicuña and the guanaco have recovered from historically low numbers in the 1960s. The potential for increase in these species is illustrated by the rise in numbers in the Pampa Galeras National Vicuña Reserve in Peru from 1000 animals in 1965 to more than 43 000 in 1979, although at least some of this increase was due to immigration of family groups to the protected area (Novoa, 1981). In the Lauca National Park in northern Chile attempts to increase numbers of vicuñas have been so successful (from an estimate of about 3000 animals in 1972 to more than 27 000 in 1991) that commercial exploitation for fibre (by capture and release) and for meat has been seriously considered and is now subject to experimentation (Rodriguez *et al*., 1987; Urquieta *et al*., 1994). The recovery of these wild species has been achieved in part due to international pressure and to increased national awareness of these unique resources, resulting, for example, in a decrease in regional exports of guanaco calf skins from 86 000 in 1978 to 10 000 in 1984. Continuing concern for the survival of the vicuña in the wild has resulted in legislation in Peru forbidding any further experimental hybridization with either the alpaca or the llama.

Table 12.1 Estimated numbers (000) of camelids in South America in the mid-1980s. (*Source*: Novoa, 1981.)

Country	Species			
	Alpaca	Llama	Vicuña	Guanaco
Argentina	1	135	23	578.7
Bolivia	324	2023	12	
Chile	47	58	30	25.0
Ecuador	a	10	a	
Peru	2687	1070	60	1.6
Total	3059	3296	125	605.3

a Ecuador has 200 alpacas and 400 vicuñas.

Types

Alpacas are smaller than llamas (Table 12.2) and are mainly used for fibre production and rarely, if ever, for transport. The skins of young alpacas are used to produce a specialized luxury fur. Both fibre and fur are important in small-scale and industrial processing. Llamas, being larger and stronger, are used mainly for transport but their fibre, which is coarser and of poorer quality than that of the alpaca, is sometimes used as a commercial product or in home industries. Meat is a by-product in both species, mainly eaten by the owners, and is mainly from culled and old animals. Neither of the species is normally milked (Calle Escobar, 1984).

Alpacas

Two major 'breeds' of alpaca are recognized. These should be considered as types, however, as both arise from two parents of the other 'breed'. No attempt has so far been made to isolate the controlling genetic factors.

The *Huacaya* (Fig. 12.4) is by far the commonest type in Peru, where 80% of the world's alpacas are found, and comprises more than 90% of the total population. The Huacaya is distinguished chiefly by the nature of its fibre which covers the whole body, the legs, the neck and the poll. The fleece is dense overall and grows perpendicularly from the skin surface. The fibre has an average diameter of about 28 µmor about 5658 s in the Bradford wool count systembut has a diameter of as much as 32 µm (48 s

Table 12.2 Physical measurements of the alpaca and llama.

Parameter	Species			
	Alpaca		Llama	
	Male	Female	Male	Female
Mature weight (kg)	85	75	110	90
Height to top of head (cm)	152	149	190	180
Height at withers (cm)	96	89	125	110

Chest circumference (cm)	115	96	125	110
Ear length (cm)		12		1618

Fig. 12.4
Huacaya male alpaca with two years of fibre growth
at La Raya, Peru.

Bradford wool count) in older females and as little as 20 µm (70 s) in young animals. The fibre is elastic and very resistant to breaking. This fibre has, in fact, been compared to the wool of Corriedale sheep.

The *Suri* type (Fig. 12.5) is much less common than the Huacaya. Its fibre has been likened to that of Lincoln Longwool sheep, although the way it falls from the centre of the back and hangs down the flanks is more reminiscent of the Wensleydale. Suri fibre averages 14 cm in length, compared to just over 10 cm in the Huacaya, and is generally slightly finer, averaging 27 µm; it is very flexible and elastic.

Llamas.

Two 'breeds' of llama are recognized. The *Ccara Sullo* is more apt as a beast of burden but produces a fibre of lower quality than the *Tapada*. Medullated fibres comprise about 2530% of the Tapada fleece but as much as 8085% of that of the Ccara sullo (Fig. 12.6). Fibre thickness in both types is about 30 µm and, when it is shorn, is

Fig. 12.5

Suri male alpaca at La Raya, Peru.

Fig. 12.6
Male animals of the Ccara Sullo (left) and Tapada (right) breeds of llama in the Altiplano of Bolivia.

used for coarser clothing than that of the alpaca, for blankets and rugs.

Guanacos and Vicuñas

These two species, except for a few experimental animals, exist only in the wild state. Guanacos

Fig. 12.7
Guanaco east of Arica in northern Chile.

(Fig. 12.7) look much like llamas but the colour of their coat is a fairly uniform reddish brown. They are found mainly in the southern regions of Argentina and Chile. The skins of young animals are much sought after but the fibre from adults is of little commercial value.

The vicuña (Fig. 12.8) is the smallest of the camelids. It produces an extremely fine quality fibre grading about 120 s on the Bradford scale (1012 µm). A characteristic feature of the Peruvian subspecies is the presence of a bib of long coarse hair down the throat and on the brisket although this is absent in the Argentinean vicuña.

Hybrids

All species of South American camelids cross freely and offspring of both sexes are usually fertile. There is, thus, a case to be made for treating all alpacas, llamas, vicuñas and guanacos as one species and according those currently taxonomically separate the status of subspecies.

There is much indiscriminate crossing between alpacas and llamas, and vice versa. It is often

Fig. 12.8
Vicuña in Chile's Lauca National Park (note the 'apron' of very fine fibre).

difficult to say from visual examination whether an animal is pure or hybrid. The alpaca-llama cross is usually known as the *Misti*, the reciprocal cross being called the *Huarizo*. Crosses between male alpacas and female vicuñas are usually referred to as a paco-vicuña.

Attempts have long been made to incorporate the very fine fibre of the vicuña into the domestic species, particularly the alpaca. The most usual cross is the male vicuña on the female alpaca as this retains much of the fineness of the vicuña coat while increasing the amount of fleece (Fig. 12.9). At the same time some wild characteristics of the vicuña are transmitted to the young which morphologically are intermediate, being of heavier build and having especially a much thicker neck than the vicuña. Back-crossing to an alpaca male produces an animal closely resembling the alpaca.

Adaptation

Domesticated South American camelids are now found only at altitudes in excess of 3500 m. Their

Fig. 12.9
(Left to right) Vicuña-alpaca cross, pure vicuña and vicuña-(vicuña-alpaca) cross.

Table 12.3 Proportions of cattle, sheep and camelids at varying altitudes in a Peruvian Andean pastoral system. (*Source*: Leyva, 1989.)

Altitude (m)	Total animals	Species (% of all animals)		
		Cattle	Sheep	Camelids
<4000	15772	10	89	1
40004300	37598	7	76	17
>4300	88050	3	31	66

comparative numerical importance increases at higher altitudes, where livestock production is the main economic activity, until they become totally dominant (Table 12.3). Other factors which affect the ratio of camelids to other stock include the amount of land farmed by a herding family, economic opportunity and socio-cultural background (Tichit & Genin, 1997). There is some evidence that before the Spanish conquest and the introduction of sheep and cattle, the camelids were more widespread at lower altitudes. Unlike Old World camelidae they do not allow their temperatures to fluctuate over a wide range from the normal 3839°C deep body temperature. Alpacas and llamas are, nonetheless, well adapted to high altitudes and to low oxygen pressures. This adaptation comprises principally a high density of red blood cells of elongated shape and large surface area, with a high affinity for oxygen and a rapid transfer of this element to, and conversion by, the body tissues.

An additional aspect of adaptation relates to nutritional physiology. Llamas in particular, but also alpacas, have lower relative intake in relation to metabolic body weight than conventional ruminants and thus probably need to spend less time foraging to achieve maintenance and production requirements (Pfister *et al*., 1989). Longer retention times of small particles in the digestive system, and the consequent higher digestibilities that are attained compared to sheep, for example, are probably also adaptations to the fibrous, highly lignified tussock grasses of the Andean altiplano and 'puna'.

A very small intercapillary diffusion pathway of 2 µm between the epitheliochorial placenta and the uterus in alpacas is also considered to be a high altitude adaptation to pregnancy (Sumar, 1985b).

Reproduction

Alpacas and llamas are generally considered to be 'slow breeders'. The usual annual reproductive rate is less than 0.5 young per breeding female. This is in part due to inadequate management and poor nutrition but also due to the extremely long, for animals of such relatively small body size, gestation period of about 345 days in each species.

Male

Anatomy

Male South American camelids have a small triangular sheath similar to that in the Old World species with musculature that directs the penis towards the rear when it is not in erection. The prepuce is fused to the glans penis until puberty. The scrotum is small and attached just below the ischial arch and close to the body. The testicles are tiny in comparison to the size of the animal, weighing only about 20 g in alpacas; most have descended into the scrotum by birth but in a few animals they do not descend from the abdominal cavity until as late as 6 months. The alpaca penis at maturity, measured from the ischiatic bone to the tip is 28 cm in length and is 1.5 cm in diameter at its widest part. A sigmoid flexion directs the penis forward for copulation.

Physiology

Male alpacas begin to express sexual interest in females at 1012 months. Most males of this age, however, still have the penopreputial adhesion, which is considered to be a sign of immaturity. The penis usually becomes free at about 14 months, when body weight is about 70% of mature weight, but may be delayed by up to 24 months. Shedding of the preputial sheath is probably related to testosterone levels which begin to approach adult levels at an average of 24 months. The lumen begins to appear in the seminiferous tubules at 12 months and immature spermatozoa are first observed at 1824 months.

There is no rut in male South American camelids as there is in the one-humped and Bactrian camels. There is some seasonality in breeding but this is partly explained by management in the domestic species. Males kept permanently with females lose libido outside a main breeding season in the austral summer from January to March. This is apparently related to rainfall and nutritional status but also to some extent to habituation to the females as when new ones are introduced sexual activity starts again. Some mating does take place at all times of the year in most areas, especially in Ecuador where young are born in every month (Hervas Ordoñez, 1994).

In experiments with captive vicuñas similar 'management' effects have been noted with regard to seasonality as observed in alpacas and llamas (Urquieta *et al*., 1994). Plasma testosterone levels in male vicuñas kept constantly with females were highest in late summer (Fig. 12.10), averaging about 20 nmol/l in the range 0.3548.00 nmol/l.

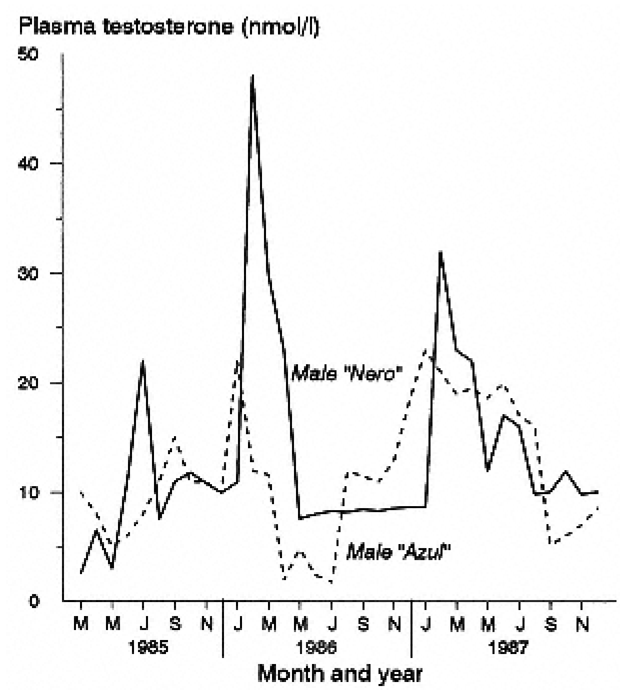

Fig. 12.10
Plasma testosterone levels in two male vicuñas with constant female presence.
(Source: Urquieta & Rojas, 1990.)

Mating Behaviour

The domestic species and the vicuña show similar mating behaviour which can be divided into courting and copulatory phases (Sumar, 1994). The first phase may be very brief with a receptive female and, indeed, a newly introduced and aggressive male may simply force the female to the ground. Copulation takes place in the sternal recumbent position (Fig. 12.11), as in Old World camels.

All unmated females are sexually responsive for most of the time. When a male is introduced into this type of flock he usually chooses the first female he finds and almost invariably she accepts him (Fernández-Baca & Novoa, 1968). Sexual activity is particularly intense in the first week after introduction of males with 7072% of females being mated at least once during this period. Males have been recorded as serving 18 females on the first day of introduction. Respon-

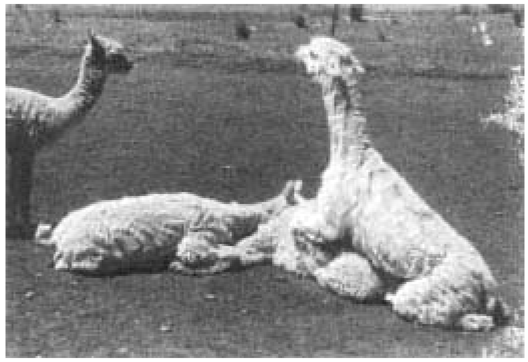

Fig. 12.11
Copulating alpaca (note the second submissive female and a third 'oestrus' female nearby).

sive females not actually being mated usually lie down or stand close to the copulating pair. During copulation the female is extremely passive while the male is very noisy, blowing and grunting. The male repositions himself constantly and deliberately during coitus, depositing semen in both horns of the uterus.

Mating takes a relatively long time; in the alpaca the copulation time is 850 minutes, with a mean of 18 minutes; in the llama mating lasts 365 minutes with a mean of 24 minutes; in the vicuña the average copulation time is 30 minutes; while in the guanaco it is 1520 minutes. There does not seem to be any relationship between the time taken to copulate and ovulation and fertilization rates.

Female.

Anatomy

Female genital organs in the llama and alpaca are morphologically similar to those in the one-humped camel but on a scale relative to body size. The vagina is about 25 cm long in the alpaca, the uterine neck 4 cm and the uterine body 16 cm. The Fallopian tube, from the ovaries to the uterus, measures about 12 cm. The uterus is T-shaped, as in the camel, with the left horn longer than the right, at least in older animals.

The placenta is diffuse and epitheliochorial in type with six tissue layers between the maternal and fetal circulation (Bustinza, 1961; Fowler, 1990a). Patchy areas of dense folded papillation serve as the placentome. The epithelium is lined with unbranched villi which correspond closely to opposing villi in the uterine wall. In late gestation both fetal and maternal epithelia are deeply indented by placental capillaries, resulting in a very small diffusion pathway from dam to young. The amnion of the full-term placenta is closely attached to either the allantois or the chorion and remains with these structures at the time of parturition. As in the camel an additional fetal membrane that covers the whole of the fetal body appears to be a product of the epidermis, probably arising from its basal layer. The delivery of young is assisted by the epidermal membrane, which is slippery, in association with the watery amniotic fluid.

The small udder has four quarters in all the South American camelids. Each teat has two streak canals and two separate glands and collecting systems, i.e. there are essentially eight glands.

Physiology

Female alpacas begin to show behavioural oestrus at about 1 year although ovarian activity begins slightly earlier, with formation of follicles of about 5 mm diameter at 10 months. Yearling females (1214 months) show oestrus and sexual behaviour similar to that of adult multiparous females and incidence of ovulations, fertilization and embryonic survival are also similar (Fernández-Baca *et al*., 1972). As in other animals sexual maturity is probably related to physical development and particularly to weight. Most yearling alpacas of 33 kg conceive but below this critical threshold the conception rate is much less. Farm practice, however, is to delay breeding of both alpacas and llamas until they are 2 years old.

There is no normal oestrous cycle in alpacas and llamas as they are induced ovulators. Release of the anterior hypophyseal ovulating hormone (luteinizing hormone) into the blood is normally brought about by copulation and most probably by one or more neural pathways

(Bravo *et al*., 1990). When not exposed to or running with males, females show long periods of receptivity of as much as 36 days, with short periods of non-receptivity that do not last longer than 48 hours. There is considerable variation in this pattern, presumably because the follicular phase in unmated females is not terminated by ovulation at a fixed time in the cycle. Similarly, there is no luteal phase to govern the chronology of events following oestrus. The long periods of receptivity and short ones of non-receptivity are probably correlated with serum oestrogen levels (which are modulated by the hypophysis) which are themselves governed by maturation and atresia of ovarian follicles. In llamas, regardless of reproductive status, the follicular wave, as established from correlations among ultrasound, hormone and behavioural data (Bravo *et al*., 1995) ranges from 12 to 15 days but in lactating animals and those with a corpus luteum there is depressed follicular development (Adams *et al*., 1990).

Ovulation occurs following an external stimulus. Copulation, with entire or vasectomized males, is most effective (Sumar, 1994) with the stimulus of artificial insemination also being relatively effective (Table 12.4). There is experimental evidence that ovulation can be caused by other mechanisms, for example by injection of 500700 IU of hCG (human chorionic gonadotropin) intramuscularly. The presence of an 'ovulation inducing factor' (OIF) in the semen of males has been postulated (Riós *et al*., 1985; Sumar, 1994). Ovulation occurs in both alpacas and llamas about 24 hours after copulation or administration of 1000 µg GnRH (gonadotropin releasing hormone) as proved by high levels of urinary pregnanediol glucoronide 48 hours after treatment; a large rounded corpus luteum is present at 5 days after copulation in animals that ovulate after stimulus (Bravo *et al*., 1992). The principal site of ovulation is the right horn of the uterus (Fernández-Baca *et al*., 1973) although, as in the camel, pregnancy is normally in the left one (Table 12.5). Migration from the right to the left uterine horn thus appears to be very common but migration in the reverse direction is very rare. The reasons for this are not fully understood. It has been shown, however, that the luteolytic activity of the right horn is local only whereas that of the left horn is both local and systemic (Fernández-Baca *et al*., 1979). This may explain the need for embryos to migrate in order to overcome the luteolytic action of the left horn which is capable of reaching the right ovary via the general circulation and causing luteolysis and early embryonic death.

Multiple ovulations occur in as many as 10%

Table 12.4 Effects of various types of stimulation on induction of ovulation in alpacas and llamas.
(*Source*: Sumar, 1994.)

Stimulus	Species and data					
	Alpaca			Llama		
	No. exposed	No. ovulating	Proportion ovulating	No. exposed	No. ovulating	Proportion ovulating
Mating by vasectomized male	5	4	60	3	3	100
Mating by intact male, ligated oviduct female	5	5	100	5	5	100
Intravaginal deposition of bovine semen	11	4	36	5	0	0
Intravaginal deposition of alpaca semen	10	6	60	8	5	67
Exposed to male without coitus	7	0	0	5	3	60
Control (no contact with males)	10	1	19	10	1	10

of cases (Sumar, 1983). Multiple fetuses are rare as most twins, as in the horse mare, are aborted, although at least 16 pairs of liveborn twin births are known in llamas (Fowler, 1990b). Multiple ovulations are slightly higher in animals injected with hCG. In overall terms about 20% of alpacas do not respond to a single copulation by ovulating and only 33% of lactating females will ovulate. Although, as discussed, there is some seasonality in the breeding season, females that are induced to ovulate have the same ovulation, fertilization and embryonic survival rates at whatever time of year they are mated.

Ovulation is followed by formation of a corpus luteum. In alpacas this reaches its full size and maximum secretory activity at about 78 days. If the mating is sterile, i.e. if the ovary is not fertilized, the activity of the corpus luteum declines sharply to day 12 and regression is complete by day 18, with new follicles being formed in the

Table 12.5 Locations of corpora lutea and embryos in alpacas.
(*Source*: Fernández-Baca *et al*., 1973.)

Location of corpora lutea	Animals	Location of embryo		
	No.%	Right horn	Left horn	
		No.	% No.	%
Right ovary	47250.9	12	2.5400	97.5
Left ovary	44047.4	3	0.7437	99.3
Both ovaries	16 1.7	0	16	100.0
Total	928100.0	15	1.6913	98.4

ovaries and a resumption of 'oestrus'. In llamas the functional life of the corpus luteum is slightly shorter, about 16 days. The changes in size of the corpus luteum are matched closely by progesterone levels in the blood, a maximum concentration of 14.3 nmol/l being observed at day 9 in alpacas, followed by a rapid fall, probably in response to repeated surge releases of prostaglandin F2a.

Following fertile mating the corpus luteum persists throughout pregnancy, maintaining its size and secretory activity and the female consequently remains sexually inactive. Progesterone levels remain high to 30 days and then reduce gradually to month 4 with a further steady reduction to month 9 although in a few cases they remain high until very close to delivery of the young. Gestation lasts about or slightly longer than 11 months in the domesticated and in the wild species; 342 and 345 days in Huacaya and Suri alpacas, respectively (San Martin *et al*., 1968); 310350 days in llamas; and 348356 days in captive vicuñas. Reproductive wastage is high with an early embryonic mortality of as much as 60% of implanted ova by day 35 after fertilization. Fetal loss from 3590 days is also high but few losses occur after 90 days of gestation. At birth the sex ratio is heavily weighted in favour of males but differential mortality results in parity between the sexes by about 6 months.

Parturition occurs in three stages (Sumar, 1985a) and takes about 193 minutes in multiparous alpaca females and 203 minutes in primiparous animals (Table 12.6). In llamas the total parturition time is shorter and takes about

Table 12.6 Total time taken for parturition (minutes) in alpacas in Peru. (*Source*: Sumar, 1985b.)

Parity	No. animals	First stage labour		Second stage labour		Third stage labour		Total time	
		Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Primiparous	34	101	77.6	24	12.8	77	38.6	203	128.0
Multiparous	96	87	67.2	25	16.0	81	39.0	193	122.0

SD = standard deviation.

176 minutes. South American camelids usually give birth in the standing position. Birth difficulties are few and dystocia is very rare. Mothers do not lick their young, placental retention is uncommon and the placenta is not eaten. Almost all births (93% in alpacas and 87% in llamas) take place between 07.00 hours and 13.00 hours and there are none at all during the cold night from 17.00 hours to 04.00 hours, this adaptation providing the best chance of survival for the young in the harsh Andean climate. Parturition is induced by the release of large amounts of prostaglandin F2a but the female appears to be able to control to some extent the timing of release. Young are born very active and are usually up and suckling within minutes of being born.

Females will accept the male within 48 hours of parturition even though regression of the corpus luteum and follicular development do not occur until 6 days post-partum. Involution of the uterus takes at least 15 days in the alpaca (Fig. 12.12) and 20 days in the llama and optimum breeding efficiency is achieved only after this time.

Artificial Insemination

Collection of semen is not easy during natural copulation because of the recumbent mating position. A practical method of collecting semen is by electro-ejaculation although a slightly higher intensity of current is needed than is used for rams. Semen from electro-ejaculations has a low sperm density of about 100 000/mm3. Natural ejaculates have higher density and greater volume so it is advantageous to collect by this method if possible. The use of an artificial vagina in a 'dummy' female is being successfully used in Peru.

Artificial insemination (AI) has been used in alpacas with fresh undiluted alpaca semen and with vicuña semen. As already indicated ovulation can be induced by the use of AI techniques. Conception rates are improved if this is accompanied by the use of a vasectomized male or by intramuscular injection of 750 IU of hCG. If the problems of low conception rates can be successfully overcome, AI in the South American camelids has considerable potential as they can

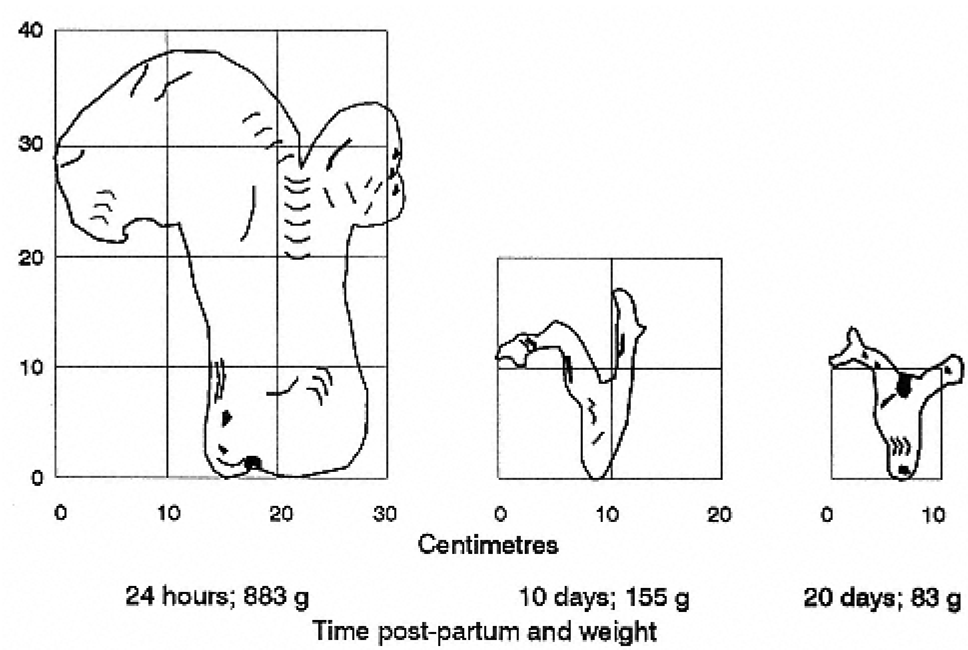

Fig. 12.12
The process of involution of the uterus in the alpaca.
(Source: Sumar *et al*., 1972.)

be served at any time and not just when they are in 'heat' as for most other domestic animals.

Pregnancy Diagnosis

The behavioural response of the females in the presence of males is an excellent means of pregnancy diagnosis. Females that show oestrous behaviour 20 or more days after service are invariably not pregnant. All pregnant females reject the male but not all that reject males are pregnant. The latter case probably represents a recent embryonic death in which the corpora lutea have not yet completely regressed. Sexual behaviour is thus a good guide to pregnancy except for these few cases where a functional corpus luteum is still present. Rectal palpation can also be performed. More modern techniques including laparoscopy and ultrasound scanning are being increasingly used in institutional flocks.

Reproductive Performance

Age at First Parturition

Males and females achieve puberty at about 12 months. In traditional systems (which have been only superficially studied) it is unusual for females to become pregnant at this age. Mating is normally delayed until 2 years with first parturition taking place at 3 years. On experimental stations in Peru about 70% of females reach 33 kg liveweight at 1 year and are mated to give birth at 2 years.

More than 85% of alpacas in Peru, and almost all llamas in their entire range, are in the hands of traditional producers. The average age at first parturition is therefore approximately 3 years although in a survey in Ecuador 789 females on 93 farms in four provinces first conceived at about 20 months to give birth for the first time at about 32 months (Hervas Ordoñez, 1994).

Parturition Interval

The interval between successive births, with a gestation period of about 11 months and a 20-day postpartum interval to mating, should enable a period of 12 months to be achieved. This seems to be hardly ever reached, however, and parturition intervals average 2 years or slightly more.

Annual Reproductive Rate

In the traditional systems the number of young per female per year rarely reaches 0.5 and 0.30.4 appears more common. With improved management on experimental farms this figure has so far been increased to about 0.7 young per female per year.

Total Lifetime Production.

Late age at first parturition, early culling or death and long birth intervals lead to a low number of young produced per female. On Peru's main camelid experimental station only 40% of females are 3 years of age or older (Fig. 12.13) and only just over 50% are 2 years or older. The maximum number of young per female, based on this herd structure, is 6.5 but average production of a breeding female is in the region of two to three. In Ecuador the range is 2.84.3 young per breeding female life (Hervas Ordoñez, 1994).

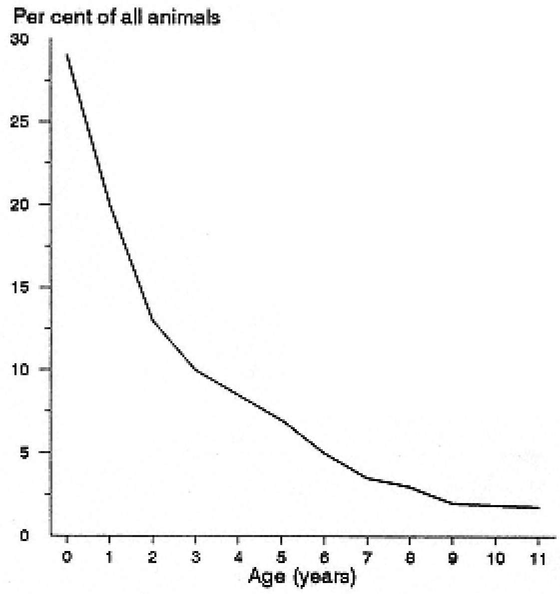

Fig. 12.13
Population structure of alpacas at La Raya farm, Peru.

Nutrition

Llamas and alpacas increase progressively in importance from altitudes of 3500 m to almost 5000 m. At the lower altitudes they are usually pastured in common with sheep, with which there is some overlap in diet composition (Pfister *et al*., 1989) (Table 12.7). At higher altitudes there are far fewer sheep and almost none at all above the limits of the common crops at about 3800 m.

There are few shrubs in the 'puna' and the vegetation consists mainly of tall tussock grasses (*Bromus catharticus, Festuca rigida, F. dolichophylla, Stipa brachiphylla*), sedges or graminoids (*Juncus microcephalus, J. macrocephalus, Scirpus rigidus, Carex* spp.), some shorter grasses, and a sparse ground cover of short grasses and herbs (*Poa fibrifera, Hordeum muticum, Agrostis breviculmis; Calamagrostis vicunarum, C. trichophylla, Alchemilla pinnata, Plantago rigida, Geranium* sp., *Trifolium* spp.). It is on this low quantity and poor quality forage that alpacas and llamas survive, produce and contribute largely to the support of their owners. Some crop by-products could be available at the lower altitudes but these are seldom fed and are usually used for fuel or for building in this largely treeless area.

The Digestive System

The anatomy of the digestive tract and many of the processes of digestion in the South American Camelidae are similar to those of the one-humped camel described in Chapter 11 to which the reader should refer.

The salivary glands of South American camelids are similar to those of true ruminants. The concentration of ions and pH values are also similar but salivary flow is greater in the camelids, allowing greater buffering capacity in the fore-stomachs. Differences occur in nitrogen, glucose, fatty acid and ketone metabolism between the Camelidae and the true ruminants. The fore-stomach proportions of volatile fatty acids (VFAs) are, however, similar, this having been interpreted as an indication that metabolic processes are similar in the two groups.

The concentration of VFAs in alpacas feeding at high altitudes is greatest about 6 hours after feeding, which is later than the peak concentrations in sheep. Greater fermentation activity is found in C1 and C2 but there is also considerable activity in the foremost two-thirds of C3, as well as in the caecum and the forepart of the colon. Higher fermentation activity of VFAs in llamas and alpacas in relation to advanced ruminants indicates almost complete absorption of these end-products of digestion from the stomach to the body tissues. In llamas fed a diet with high energy but low protein the urea recycling rate can reach 95%. In llamas provided with diets containing the same level of energy but different levels of protein, animals on low protein use 78% of nitrogen from recycled urea in metabolism, but animals fed a diet adequate in protein use only 10% of recycled urea nitrogen.

Table 12.7 Dietary composition (%) of llamas, alpacas and sheep in the Peruvian Andes. (*Source*: Pfister *et al*., 1989.)

Vegetation type	Dry season (July)			Wet season (January)		
	Llamas	Alpacas	Sheep	Llamas	Alpacas	Sheep
Tall grasses (0.51.5 m)	36	24	17	45	28	20
Short grasses (<0.3 m)	51	36	43	52	29	66
Graminoids	6	2	3	5	1	1
Herbs (<0.3 m and mat forming)	4	35	35	7	42	13
Similarity indexa	39	31	26	53	35	27

a Between selected diet and forage on offer; smaller indices indicate greater selectivity.

Feed Preferences

The llama, whose stomach capacity is in the region of 11 litres, is a bulk and roughage feeder whereas the alpaca is more selective. There is considerable complementarity between llama and alpaca diets (Pfister *et al*., 1989; San Martin & Bryant, 1989) but the latter tend to feed on the ground layer of very short grasses and herbs while the former show a predilection for the taller and coarser grasses and sedges. In the wet season there is more similarity between the diets of the two camelid species than in the dry season, as alpacas graze the new shoots of the taller species. Guanacos in Argentina prefer to eat grasses such as *Panicum, Poa* and *Sporobolus* species rather than shrubs but they are often driven out of areas where domestic cattle are in competition with them (Puig *et al*., 1997).

Grass consumption is generally higher during the dry season, herbs contributing more to the diet in the dry season. Herbs, especially legumes, do not form a large proportion of the diets of alpacas and llamas and this may be a reason why bloat has not been reported for these species. On the same pasture, sheep consume about 2.5 times more legumes (43 versus 18%) than do alpacas and llamas, which consume about 1.4 times more grass (83 versus 60%).

Grazing Behaviour

Llamas and alpacas spend about 75% of their daytime activity at pasture grazing, compared to 60% by sheep in the same environment. Most time is spent grazing by all species at the end of the rains and early in the dry season, least time at the end of the dry season, and an intermediate time in the middle dry season. In the Lauca National Park in northern Chile, at an altitude of 4500 m, alpacas spend 380 minutes per day in actual feeding time and walk 3.2 km in search of feed (Raggi *et al*., 1994).

Resting occupies 14, 10 and 22% of time in llamas, alpacas and sheep; this activity is higher in all species at the end of the dry season than at other periods and is very high (42.5%) in sheep. Other activities include walking, in which there is little seasonal variation and on which slightly more time is spent by sheep than by the camelids; and ruminating, on which very little time is spent by llamas (1.6%), more by alpacas (3.3%) and considerably more by sheep (7.9%). South American camelids that are herded during the day obviously pass a large part of the night in rumination.

Time spent at a particular feeding station (defined as a period when animals do not move their front feet) is similar for llamas and alpacas in the wet period. Both species diverge greatly from sheep, which spend a very much shorter time at a feeding station, especially in the early rains. More time is spent at a feeding station by all species in the dry season. Feeding station times are shorter when forage availability is greater (Pfister *et al*., 1989).

Camelids have faster bite rates in the late rains and early dry season than in the late dry season and early rains. Llamas always have a higher bite rate than alpacas. Sheep, in contrast, have an increased bite rate in the early rains which exceeds that of llamas at this period. It is considered that very short times per feeding station and rapid bite rates in a period of increasing forage quantity and quality indicate the more selective nature of sheep compared to the camelids.

Intake

Overall average intake is relatively low in llamas and alpacas in relation to body weight or metabolic body weight (San Martin & Bryant, 1989). In alpacas daily dry matter intake (DDMI) has been shown to be about 1.8% of liveweight and in llamas is about 2.0%. In comparison with sheep, with a DDMI of 3.04.0%, the camelids consume about 3540% less per unit weight. Daily organic matter intake is also less in llamas (about 50% of metabolic body weight) than in sheep (about 90% of metabolic weight).

Lower intakes by the camelids are probably related to the larger body size and relatively lower energy requirements. This allows llamas and alpacas to be less selective in choosing plant parts than the smaller sheep with smaller mouths.

Digestibility

Llamas usually have higher digestibility coefficients of major feed components than do sheep, except for crude protein (Table 12.8). They are more efficient at digesting dry matter and cell wall constituents than sheep or ponies (Hintz *et al*., 1973) or cattle (San Martin *et al*., 1984). As diet quality increases digestibility coefficients of sheep approach those of llamas. Alpacas are better able to digest dry matter, crude protein and crude fibre than sheep on low quality diets of under 7.5% protein but the reverse is true on high-quality diets with a protein content greater than 10.5% (Pfister *et al*., 1989).

Greater efficiency in digestion by the camelids is probably related to retention time of the solid digesta in the stomach (Wilson, 1989; von Engelhardt *et al*., 1992). Retention time of solid particles is about 50 hours in alpacas, 63 in llamas and 4143 in sheep. Liquid flow in the camelid digestive system is, however, faster than in sheep. In llamas a shorter liquid retention time is probably related to greater relative salivary flow which improves microbial protein synthesis. Shorter liquid retention times improve microbial growth and ensure that a minimum amount of energy is required to maintain microbial populations.

Nitrogen requirements are lower in camelids than in sheep, being 2.38 g/kg protein W0.75 for alpacas and 2.79 g/kg W0.75 in sheep. On low protein diets, llamas recycle more body urea than true ruminants and use 85% of what is recycled. Maintenance requirements of metabolizable energy are also lower in the South American camelids than in sheep and goats due to a lower basal body metabolism. Llamas can reduce energy expenditure from 61 kcal/kg W0.75 to 52 kcal when on restricted feed, a value lower than the fasting metabolism of true ruminants. High digestibilities in the camelids are probably also related to frequent stomach contractions, the rumination cycle, and a high ratio of salivary flow to fore-stomach volume (von Engelhardt *et al*., 1988; Lechner-Doll *et al*., 1991). On low nitrogen intake camelids probably maintain higher ammonium concentrations in the fore-stomachs, providing more nitrogen for microbial synthesis and thus improving digestibility.

Health

Most alpacas and llamas are managed under what would generally be considered as less than optimal sanitary conditions. They are packed closely into small enclosures at night, providing a

Table 12.8 Digestibility coefficients (%) in llamas and sheep on different quality diets. (*Source*: San Martin & Bryant, 1989.)

Feed component	Diet quality and animal species							
	Low 7% CP 2.2 Mcal DE/kg DM		Medium 11% CP 2.8 Mcal DE/kg DM		High 15% CP 3.2 Mcal DE/kg DM		Overall	
	Llamas	Sheep	Llamas	Sheep	Llamas	Sheep	Llamas	Sheep
Acid detergent fibre	47	42	40	34	46	41	44	39
Crude protein	24	19	38	37	68	73	43	43
Neutral detergent fibre	43	33	43	32	40	40	42	35
Organic matter	51	41	80	52	73	75	62	56

CP = crude protein; DE = digestible energy; DM = dry matter.

favourable environment for the transmission of infectious and parasitic diseases. Both species, at least after weaning, appear to be relatively resistant to disease and mortality rates are less than in comparable age groups of other domestic animals.

Newborn South American camelids, like their Old World counterparts and in contrast to adults, are delicate and fragile beings and suffer heavy mortality. Part of the reason for this is undoubtedly the fact that passive immunity to disease organisms is not transmitted from dam to fetus across the epitheliochorial placenta. Passive immunity is acquired via the colostrum, which is essential early nourishment for the young. Llamas and alpacas are born with very low levels of serum proteins and levels rise only on suckling colostrum. Gamma globulin concentrations are also low at birth as a result of low protein levels, even though globulins comprise as much as 90% of total proteins. A rapid progressive reduction in immunoglobulins IgG and IgM, which are not transmitted in the colostrum, from 1 day after birth to 3 weeks renders the newborn animal very susceptible to disease.

In the Puno area of southern Peru average annual mortalities over a 7-year period were 27% for young animals before weaning, 5% for weaned animals and 3% for adults. Infectious diseases were implicated in the deaths of 66% of young and in more than 50% of weaners and adults. Parasitic infections, in contrast, were directly responsible for few deaths; less then 1 % in young and 35% in the older classes. Accidents and organic causes (internal bleeding, asphyxia, hereditary defects, intestinal torsion, ruptures) were responsible for many deaths. Predators, particularly puma and foxes, were also responsible for some losses (S.M. Moro (1970) pers. comm., in Calle Escobar, 1984).

Infectious Diseases

Enterotoxaemia caused by *Clostridium perfringens* types A and C and pneumonia are the major causes of loss in neonatal and young alpacas although they suffer from many other diseases (Table 12.9) including alpaca fever (due to *Streptococcus pyogenes*), coli-bacillosis, osteomyelitis and peritonitis. In older animals alpaca fever, clostridial disease (due to *C. septicum* and which causes sudden death), pneumonia, osteomyelitis and otitis are the major causes of loss (although for the last two, animals are usually slaughtered for meat before death occurs). Peritonitis, metritis and enteritis are also relatively important diseases in older animals (S.M. Moro (1970) pers. comm., in Calle Escobar, 1984).

Some infectious diseases common in cattle and other ruminants are either very rare or unknown in the South American camelids. These include anthrax, blackquarter, vesicular stomatitis and foot-and-mouth disease. Brucellosis or contagious abortion, due to *Brucella melitensis* which is the common pathogen of goats and sheep, does, however, occur.

Parasitic Diseases.

Diseases caused by internal and external parasites (Table 12.10) are responsible for few deaths but cause considerable economic loss (S.M. Moro (1970) pers. comm., in Calle Escobar, 1984). Attention to hygiene, and particularly the cleaning or frequent movement of night pens, to reduce the incidence of gastrointestinal diarrhoea has, for example, shown enormous benefits.

Many nematodes of alpacas and llamas are peculiar to these animals, as indicated by their generic or specific names. Thus the most common internal parasites are *Graphinema aucheniae*, *Nematodirus lamae* and *Lamanema chavezi* (Chavez & Guerrero, 1965). Some species common to true ruminants such as *Ostertagia*, *Trichostrongylus*, *Cooperia*, *Nematodirus*, *Oesophagostomum* and *Haemonchus*, while present, appear to be of lesser importance. Lungworm, due to *Dictyocaulus filaria*, is a major cause of economic loss in the more humid areas of the South American camelids' range.

Some worldwide zoonoses, in addition to brucellosis, are also present in alpacas and llamas. These include hydatid disease (*Echinococcus granulosus*), sarcocystiosis (due in this case to camel-specific *Sarcocystis aucheniae* and *S.*

Table 12.9 Major infectious diseases of alpacas. (*Source*: S.M. Moro (1970) pers. comm., quoted in Calle Escobar, 1984.)

Disease	Cause	Animals affected	Source of infection	Morbidity	Mortality	Control
Alpaca fever	*Streptococcus pyogenes*	Young 12, years + adults under stress	Opportunistic parasite	Low-high	High	Avoid stress, antibiotics
Braxy	*Clostridium septicum*	Animals with wounds or overfat	Injuries	Low	High	Vaccination, good management
Enterotoxaemia	*Clostridium perfringens/ welchii* Types A & C	Strong young, 1040 days	Digestive tract	High	High	Vaccination of dams, good management, antibiotics
Keratitis	*Corynebacterium pyogenes*	Young stock	Dust	Occasionally high	Low	Antibiotics
Metritis	*Staphylococcus zooepidemicus/ aureus*	Females after parturition	Infection of wounds	Medium	Low	Antibiotis
Necrotic stomatitis	*Spherophorus necrophorus*	Young 45 months + yearlings	Mouth wounds	Usually low	High	Preventive treatment of mouth injuries
Otitis	*Corynebacterium pyogenes*	Animals >6 months	Mechanical damage	Medium	High	Surgery, antibiotics

lamaranis) and toxoplasmosis (*Toxoplasma gondii*). The zoonoses cause direct economic loss not only in lowered animal productivity but also in condemnations at slaughter and in inducing ill health in humans who eat meat of animals not inspected and condemned. Coccidiosis, tapeworms (*Moniezia* and *Thisaniezia* spp.) and liver fluke (*Fasciola hepatica*) also infest llamas and alpacas and cause loss.

The most prevalent and costly external parasites are the mange-producing mites. Distinctive varieties (e.g. *Sarcoptes scabiei* var. *aucheniae*) or species (*Psoroptes aucheniae*) have developed in the Andes and are more or less confined to camelids.

Management

Alpacas and llamas are small and docile animals that live in close proximity, even in symbiosis, with their owners. In Peru almost 85% of alpacas are owned by 'campesinos' or peasants; another 7% are owned by people classed as small- and medium-stock raisers, usually in herds ranging in size from 100 to 500 head; and about 9% are owned by co-operative groups formed under the agrarian reform laws of the late 1960s and the 1970s. In Bolivia and Chile almost all alpacas are in the hands of peasant producers.

Control

In the traditional systems animals are herded by one person, often a child, while at grazing. Flocks are often communal (although animal ownership is usually private) and are grazed on commonly owned land in mixed sex, age and species units. Alpacas and llamas forage in loose groupswhich probably resemble the natural social and foraging strategies of the wild speciesand re-

Table 12.10 Major parasitic diseases of alpacas. (*Source*: S.M. Moro (1970) pers. comm., quoted in Calle Escobar, 1984.)

Disease	Cause	Animals affected	Site of infection	Life cycle	Control
Coccidiosis	*Eimeria* spp.	Mainly young	Small intestine	Direct	Sulphur drugs
Gastrointestinal parasites	Many roundworms	All ages	Intestines	Direct	Rotational grazing, anthelmintics
	Many tapeworms	All ages	Intestines	Indirect	Rotational grazing, control of secondary hosts, anthemintics
Hydatidosis/ cysticercosis	Various species	All ages	Liver, lungs, muscles	Indirect	Rotational grazing, control of secondary hosts, anthemintics
Mange	*Sarcoptes scabiei* var. *aucheniae, Psoroptes communis* var. *aucheniae*	All ages	Skin	Direct	Dips, pour on insecticides
Sarcocystiosis	*Sarcocystis aucheniae*	Adults >2 years	Oesophagus, heart, neck and chest muscles	Direct	
Verminous bronchitis (lungworm)	*Dictyocaulus* spp.	Mainly young	Lungs	Direct	Rotational grazing, anthelmintics

spond to the spoken or whistled commands of their herders. An area of the range is usually chosen by the animals as a dust bath and in which they roll. Herding is done only by day, confinement at night being in a rather small enclosure attached, or close to, the main family dwelling. Even in such a small area both species of domestic camelids deposit their faeces at predilection sites.

Llamas can be trained easily to the halter but when used for transport, singly or in convoy, they are normally driven and directed by spoken commands.

Identification

Animals are known to their owners and are rarely marked for identification. Within some larger herds and co-operative groups ears are notched to denote particular ownership.

Reproductive Performance

Poor reproductive performance in traditionally managed alpaca and llama herds is in part attributed to the constant presence of females with males. Under experimental conditions 75% of females are served during the first week following introduction of males but after this a sharp reduction in male sexual activity occurs (Sumar, 1985a). This reduction is not due to a lack of receptive females but to inhibition of male libido in the presence of the same group of females. It is therefore recommended that males (always in the proportion of 3% of females or one male to 3035 females) be introduced only for short periods or, where used constantly, be rotated at intervals of not more than 15 days among different groups of females. Some owners control breeding in mixed sex and species herds by the use of a rope round the penis attached over the back

(which is protected by a pad) of the animal (Fig. 12.14). No experimental work has been done on the effects of this continuous presence and prevention of sexual access on the overall reproductive rate.

Under the open management system just described most births take place in December to March. In theory, year-round breeding is possible using either the 'male effect' by introducing males for short periods, or by rotation of males. In practice it might not always be advisable to have young born in the depths of the Andean

Fig. 12.14
A traditional contraceptive device in the form of a cord round the penis, supported by a sack on the back, on a llama at Salar de Surure, Chile.

winter (MaySeptember) unless adequate feed and shelter can be provided.

Dentition and Age

Llamas and alpacas have dental formulae similar to those of Old World camels (see Chapter 11). These species also differ from true ruminants in the presence of canine teeth, somewhat reduced in females, in their permanent dentition. Alpacas and llamas can be aged quite easily up to 7 years by dental development (Table 12.11). Beyond 7 years ageing animals by their teeth is more difficult and dependent to a great extent on experience.

Productivity

Fibre

The alpaca is the main producer of fibre (Condorena, 1980) but its average yield of 1.8 kg (Table 12.12) (range 0.94.0 kg), and to some extent its quality, do not compare to that of sheep. The heritability of fleece weight is yet to be estimated but the great variation in yield suggests that it might be high. Shearing is done every year or every second year with the useful productive life of castrated males being 1012 years. The advantages of annual shearing are:

Table 12.11 Temporal evolution of the teeth in alpacas and llamas. (*Source*: Calle Escobar, 1984.)

Jaw and teeth	Sex	Age at eruption	Full development
Lower			
Central temporary incisors	Both	07 days	10 days
Median temporary incisors	Both	1484 days	6090 days
Outer temporary incisors	Both	67 days	120300 days
Central permanent incisors	Both	2.53.0 years	3.03.5 years

Median permanent incisors	Both	3.54.0 years	4.04.5 years
Outer temporary incisors	Both	4.5 years	5.0 years
Canines	Male	2.5 years	3.54.0 years
	Female	3.4 years	5.0 years
Upper			
Permanent incisors	Male	3.0 years	3.54.0 years
	Female	5.3 years	5.0 years
Canines	Male	3.2 years	3.54.0 years
	Female	6.1 years	7.0 years

Table 12.12 Fibre production by two breeds of alpaca in Peru. (*Source*: Condorena, 1980.)

No. shearings	Huacaya breed			Suri breed		
	No.	Liveweight (kg)	Fleece weight (kg)	No.	Liveweight (kg)	Fleece weight (kg)
1	3659	28.2	1.20	506	28.1	1.34
2	2716	47.2	1.74	375	46.5	1.74
3	2644	54.2	1.90	373	55.9	1.91
4	2040	58.0	1.75	331	59.9	1.80
5	1699	59.8	1.75	261	61.1	1.79
6	1433	61.7	1.74	282	62.7	1.68
7	1097	63.2	1.71	225	64.9	1.72
8	801	64.1	1.68	190	64.3	1.66
9	600	64.9	1.62	125	65.6	1.61
10	405	65.9	1.63	97	66.4	1.51
11	284	64.8	1.61	66	65.7	1.49
12	221	64.8	1.58	66	65.7	1.49

- There is less damage to the fibre by solar radiation and other environmental factors.
- Fibre growth in the second year is only about 6065% of that in the first year.
- Poor producers can be detected and culled earlier.
- Control of external parasites, especially mange, is easier.

Average fibre length is in the range 711 cm. Unlike the other three South American camel species, the alpaca is single-coated and produces a fleece with a mean fibre diameter in the range 2125 µm (Russel, 1994). The llama is double-coated with an undercoat which has a mean fibre diameter in excess of 30 µm. The guanaco is also double-coated, but the undercoat is much finer than that of the llama, with a fibre diameter of 1518 µm, which is similar to that of cashmere goats. The double-coated vicuña is still listed as endangered by the International Union for the Conservation of Nature (IUCNnow known as the World Conservation Union) (although as indicated populations seem to be recovering), a state resulting from it having the finest of all undercoats with a mean fibre diameter of 1113 µm.

In all South Americana camelids, hair fibres are produced from primary and secondary skin follicles (Russel, 1994). In the double-coated species the primary follicles produce the coarse outer coat of guard hair while the secondary follicles produce the fine undercoat. In the alpaca the fibres of both follicle types are of the same diameter. As in sheep and goats, the follicles are arranged in groups with a variable number of secondaries associated with each primary; the average number of secondaries (s) to primaries (p)the S/P ratiois about 5.5:1.0. Since follicles are formed *in utero* and no new ones are initiated after birth, the S/P ratio is a characteristic of each individual. Follicle density decreases with age as the animal grows, a typical value for adults being about 17 per mm2.

The alpaca differs from the other camelids, not only in having a fleece of only one type of fibre, but also in having fibre which grows continuously without shedding. The double-coated species shed their coats annually, with the undercoats and guard coats moulting at different times. These species therefore never have long fleeces. In terms of fibre biology, the llama, guanaco and vicuña are similar to the cashmere goat, having a double coat which grows seasonally and is shed annually, while the alpaca resembles improved breeds of sheep and the Angora goat in having a single coat which grows continuously and is not normally shed (Russel, 1994).

There is overlap among the species in mean fibre diameter, and this measurement alone can not be used to determine whether a fibre is from a particular species. Colour may be helpful in identifying fibres of different species but is not always so. Microscopic examination may be of use in identification as the characteristics of the scales which comprise the cuticle or outer layer of each fibre differ among species, those of the alpaca being much smaller and smoother than those, for example, from llamas (Fig. 12.15).

Unlike wool and cashmere, the majority (about 80%) of even the fine camelid fibres are medullated (i.e. they are hollow-shafted). The hollow is completely empty or filled with a honeycomb-like structure which may run almost the entire length of the fibre or just occur in sections. This feature is important in giving camelid fibre its unique qualities and makes it particularly light in relation to its volume or bulk.

There are indications of a strong positive correlation between the proportion of medullated fibres and their mean diameter, implying that coarser fibres are more likely to be medullated. There is, however, no apparent relationship between undercoat weight and mean fibre diameter, i.e. between quantity and quality. This contrasts with other species in which animals producing most fibre usually have the poorest quality and vice versa. Selection of breeding stock on the basis of production should not prejudice fibre quality, and animals could be bred for fibre quality without necessarily incurring a penalty in fleece weight.

Recent results (Russel, 1994) indicate that undercoat weight is closely related to fibre length, which can easily be measured. In selecting breeding stock for fibre it might be possible to use length to identify the best animals. The relation between undercoat weight and length is such that each centimetre is equivalent to a fibre weight of about 160 g in a 100 kg animal. Guard hair measurements also show that its weight is related to undercoat weight but that length is an equally good or better predictor of undercoat weight with each centimetre of guard hair length yielding about 55 g of undercoat in a 100 kg animal.

Transport

Considering the historical and continuing importance of llamas as pack animals there are very few objective data on performance. It is said that only males are used for transport and carry 2535 kg depending on the terrain and the distance, although in North America experienced packers load as much as 45 kg (Murray Fowler (1997), pers. comm.).

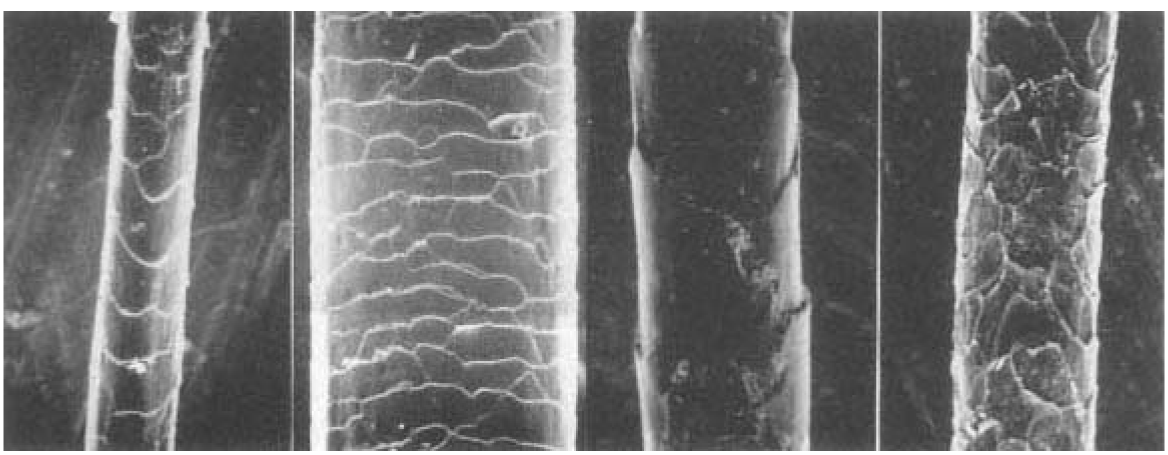

Fig. 12.15
Differences in size, height:width ratio and smoothness of cuticular scale patterns, from left to right, in the llama, alpaca, cashmere goat and wool sheep.
(Source: Russel, 1994. Photograph courtesy of A.J.F. Russel.)

Meat.

Offtake rates of both alpacas and llamas in Peru are estimated to be 811% in traditional herds, which produces an annual fresh meat equivalent of about 11 000 t of alpaca and 3500 t of llama (Calle Escobar, 1984). The taste of alpaca meat is said to be similar to or superior to that of mutton. Carcase yields of alpaca from males weighing about 150 kg and females weighing about 130 kg are in the range 4952% (although sometimes as high as 60% (Calderón & Fernández-Baca, 1972)), those of llama being 4448%. The meat: bone ratio is about 3.4:1.0.

Most meat of the alpaca and the llama is produced at the end of a useful life as a fibre producer or as a transport animal, and is used for home consumption. Males are usually slaughtered at 34 years and females at 68 years. The nutritive value of camelid meat differs in some respects from that of the other common meat animals (Table 12.13). Meat of both the domesticated species is relatively high in protein and low in fat and hence in energy.

'Charqui' is a favourite form of dried meat for many peasant farmers, easy to prepare in the Andean winter and a store of high quality animal protein. Salt is used by most 'campesinos' in the traditional drying process but a very small proportion is dried without it and a similar small

Table 12.13 Proximate composition of meats of South American domestic animals. (*Source*: Calle Escobar, 1984.)

Species	Gross composition (%)			
	Moisture	Protein	Fat	Ash
Alpaca	74.5	21.3	4.1	1.4
Llama (fresh)	69.2	24.8	3.7	1.4
Llama ('charqui')	22.8	24.8	3.7	3.3
Cattle (beef)	72.7	21.0	4.8	0.9
Sheep (mutton)	72.2	18.9	6.5	2.2
Goat	73.8	20.6	4.3	1.3
Pig (pork)	59.2	19.4	20.1	0.0
Fowl	72.0	21.9	3.8	1.3
Duck	70.1	19.6	7.9	1.5
Turkey	70.0	22.2	5.2	1.4

proportion has sugar added. The product is eaten in the dry state or rehydrated and cooked.

Milk

Milk is not usually an economic product and there are no data on total production although it is said that 2 litres can be produced in a 24-hour period. Fat content is in the range 27% (Jimenez, 1970).

Constraints to Increased Productivity and Opportunities for Development

There are several technical, socioeconomic and constitutional constraints to increasing the productivity of the South American camelids and thus their contribution to human welfare.

Alpacas and llamas feed almost exclusively on high altitude pastures and rarely receive feed supplements. Pasture is adequate in quantity and quality over most of their ranges in the summer (DecemberMarch) but at other times there are deficiencies in the feed supply. Some reproductive problems may be associated with inadequate nutrition or imbalances in energy and protein. No mineral or trace element deficiencies are reported but it is likely that these occur. Research is in progress on improving nutrition but if overall productivity is to be increased the results must be applicable to, and widely adopted by, the small-scale producers who own the majority of the alpacas and llamas.

Low reproduction rates are a major problem on most farms. The overall annual reproductive rate is only about 0.5

young per breeding female per year. This is not only an economic loss but limits the potential for rapid genetic improvement. Poor reproductive performance is a consequence of genetic factors, nutrition, health and management. Much has been learnt in recent years, certainly about the factors governing the reproductive process and about nutrition, but optimum performance will only be achieved through an integrated and pluridisciplinary approach to the problem. Proposed solutions must

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be acceptable to the owners who should also benefit from better extension advice than they now receive.

Poor health lowers performance in all spheres not only through mortality but also from the morbidity that leads to slow growth rates and poor reproductive performance. Solutions to this problem where producers are widely scattered, far from population centres and own few animals individually will not be easy but must be found if the South American camelids are to perform to their full potential.

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13
Donkeys, Horses and Mules

Introduction

Equines provide little as meat and milk to food supplies in the tropics. Probably mainly because of this they are less numerous than other stock and their major contribution to agriculture and to human welfare is draught and other power functions. In today's world equines are a low-cost alternative to mechanization, more accessible to tropical farmers with limited resources and make a contribution to sustainable agriculture.

The merits of equines in providing power include:

• Intelligence

• Docility

• Speed

• Agility

• Effective weight to work ratio

• Strength

• Conservative water needs

• Longevity.

Donkeys are the most numerous tropical equines, probably because they possess some of these merits in greater measure than the horse or the mule. Their lack of size, speed and strength is compensated for by thriftiness, hardiness and disease resistance. Horses are relatively unimportant numerically in Africa except in Ethiopia but are by far the most abundant species in Latin America; in Asia donkeys and horses are present in almost equal numbers.

Origins and Ancestry

Horses and donkeys (and their crosses, the mule and the hinny) belong to the family Equidae in the order Perissodactyla. *Equus* is the only extant genus in the family. The earliest recognized equid was *Hyracotherium* (also known as the 'dawn horse') which was widely distributed in North America and Eurasia at the start of the Eocene period. During the Pliocene there were several equid genera including *Hypohippus*, *Parahippus*, *Anchitherium* and *Neohipparion*. These types disappeared in the Pleistocene and only *Hipparion*, in addition to *Equus* (which had first emerged during the Miocene), survived.

Early horses were probably mixed feeders that later became adapted to feeding on plants. Equids are now highly specialized grazing animals with teeth structures peculiar to the family. The foot is reduced to one toe that is particularly adapted for fast running.

The surviving genus is classed into four groups. These are: true horses (*Equus caballus*); pseudo-asses of the *E. hemionus* group; true asses (*E. asinus*); and quaggas (*E. quagga*, *E. greyvi*, etc.). The original ranges of these groups are thought to have been the whole of Europe and Northern Asia for horses, West, Central and Southern Asia for pseudo-asses, North and Northeast Africa for donkeys and Africa south of the Sahara for zebras and quaggas. There are several living species of wild equids, mostly in Africa. These include the

zebras (*E. quagga, E. greyvi*) and the ass (*E. asinus*).

There are two subspecies of the wild ass, the Nubian (*E. asinus africanus*) and the Somali (*E.a. somalicus*). The Nubian formerly ranged over the area between the Nile and the Red Sea and probably into Eritrea but its numbers and distribution are now greatly restricted. It measures 120130 cm at the withers, has a large head, long ears and large hooves. The coat colour is reddish or bluish grey in summer and sandy grey in winter. The colour is lighter ('mealy') around the muzzle, along the underside of the body and in the inguinal region and the insides of the legs. There is a back stripe with a shoulder cross but there is no barring on the legs.

Many domestic donkeys do have barring on the legs which is a characteristic of the Somali wild ass which is larger than the Nubian, has stronger colouring and usually lacks the shoulder cross. It is mainly found in northern Somalia and until recent times was present in the Ogaden, the Danakil Depression and along the Red Sea littoral as far north as Eritrea. If the influence of the Somali wild ass on the gene pool of the domestic donkey is admitted it is solely because of the presence of leg stripes.

The large Muscat or 'Syrian' donkey is considered by some to be descended from the onager, *E. hemionus*, but others (Epstein, 1971) dispute this. Zeuner (1963) and others believe that all domestic asses in Asia are descended from the onager. This theory agrees with the commonly accepted one that true wild asses never extended their geographical range outside Africa. More recent evidence suggests that wild *E. asinus* may have been present in Western Asia some 10 000 years ago and that there was a separate centre of domestication in that region (Ducos, 1970, 1975; Clutton-Brock, 1978).

In some classifications Przewalski's horse (*E. przewalskii*) is considered a subspecies of *E. ferus*, widely regarded as the single progenitor of the present domestic horse. Przewalski's horse is also known as the 'taki' (*E.f. przewalskii*), the other subspeciesprobably the main ancestor of the horsebeing the 'tarpan' (*E.f. gmelini*). The modern domestic horse is, however, named *Equus caballus*.

Domestication

Donkeys and horses were domesticated for reasons fundamentally different from those of the pig, cattle, goats and sheep; these were primarily domesticated to create additional sources of protein. The horse family was not domesticated until other uses for animals had been discovered and accepted and, although equids were originallyand in some cases still areused as food, they have mainly been draught and transport animals throughout history.

True wild asses never occurred outside Africa and it is almost certain that domestication took place here (Protsch & Berger, 1973), probably in the northeast corner where *E.a. africanus* had its domain. The major evidence for domestication is from Egypt, where rock paintings of a donkey with a back-pack tied by girths date from about 6000 BP (before present). At about 4500 BP donkeys were common in Dynastic Egypt as shown by paintings and artifacts in tombs. By 5000 BP donkeys had spread to Southwest Asia and 4000 years ago they were well established in South Asia. Donkeys were never numerous in Europe, probably because of colder and wetter conditions there, and a climate more suited to horses.

Horses appear to have been first domesticated in Eastern Europe, in the Ukraine, about 5500 years BP. The evidence is the large number of horse bones (60% of all animal bones) at Ukraine sites, changes in skull and teeth shape and, most convincingly, from the number of mouth bits made of deer antler. Domestication possibly took place separately in Western Europe and almost certainly did on the Western and Central Asian steppes, where *E.f. przewalskii* would have been the progenitor. Once domesticated, horses spread rapidly northward into Russia and eastward into Western Asia. Horses were plentiful in Western Europe during the Bronze Age, about 4000 BP, and were common in Greece a short time later.

Numbers and Distribution

Equine distribution basically reflects the centres of origin and physiological adaptations of horses and donkeys. In the tropics, horses are usually more numerous in cooler and moister areas or at higher altitudes. Donkeys are commonest in the harsher climates of semi-arid and arid areas. The distribution and numbers of horses are limited by African Horse Sickness. Cultural and historical factors also affect equine distribution, especially mules.

In world terms, it is Asia that has most horses, mules and donkeys but by far the majority of these are in China. Donkeys and mules are virtually totally absent from the whole of humid Southeast Asia; in some countries in this region horses are not uncommon and occur at relatively high densities but at a low ratio to the human population (Table 13.1). In South Asia, Bangladesh has very few donkeys while both India and Pakistan (which has the third largest number of donkeys of all countries in the world) have large numbers at relatively high densities but again at a low ratio to humans.

South America is the one major tropical area where horses are more numerous than donkeys (Table 13.1). This area is also peculiar in that mules are often preferred to donkeys and in total numbers mules are about at parity with donkeys.

Table 13.1 Numbers, density and ratio to humans of equines in some selected areas and countries. (*Source*: adapted from FAO, 1995.)

Continent/ country	Horses No. (000) Density (No./km2)a	Horses No./ personb	Mules No. (000) Density (No./km2)a	Mules No./ personb	Donkeys No. (000)	Donkeys Density (No./km2)a	Donkeys No./ personb
Africa	4 7580.160	0.012	1 3940.047	0.003	13 408	0.452	0.032
Egypt	100.010	0.000	10.001	0.000	1 650	1.658	0.070
Ethiopia	2 7502.750	0.070	6300.630	0.016	5 200	5.200	0.132
Kenya	20.003	0.000	n.a.n.a.	n.a.	n.a.	n.a.	n.a.
Mali	1010.083	0.123			611	0.501	0.074
Nigeria	2040.224	0.003			1 033	1.134	0.015
Sudan	230.010	0.001	10.000	0.000	675	0.284	0.044
Zimbabwe	240.062	0.003	10.000	0.000	104	0.268	0.014
Asia	16 0070.600	0.009	6 1240.229	0.003	21 325	0.796	0.012
China	9 9601.068	0.013	5 4980.591	0.007	10 886	1.167	0.014
India	9900.333	0.001	1440.048	0.000	1 600	0.538	0.003
Indonesia	7140.395	0.002					
Malaysia	50.015	0.001					
Sri Lanka	20.031	0.000					
Vietnam	1340.421	0.003					
Yemen	30.006	0.001			500	0.947	0.067
South America	14 4930.827	0.171	3 4510.197	0.051	4 105	0.234	0.061
Bolivia	3240.299	0.114	810.075	0.028	636	0.587	0.223
	5 8000.686	0.166	2 0900.247	0.060	1 370	0.162	0.039

Brazil							
	5351.932	0.173	1580.570	0.051	274	0.990	0.089
Ecuador							
	6660.520	0.083	2250.176	0.028	523	0.409	0.065
Peru							
	4792.740	1.177	40.023	0.010	1	0.006	0.002
Uruguay							
World	58 1580.530	0.024	14 9520.136	0.006	43 792	0.399	0.018

n.a. = not available.

a Area used to calculate density is total land area.

b Figure used to calculate ratio to people is total agricultural population.

Brazil, Ecuador and Uruguay have a high density of horses and Uruguay has a very high horse: human ratio. Conversely, Uruguay is almost devoid of donkeys and has very few mules while Bolivia has a relatively dense population of donkeys but few mules and Ecuador has high densities of mules and donkeys and a relatively high donkey: human ratio.

Donkeys are far more common in Africa than horses and, except in Ethiopia and Morocco, there are relatively few mules (Table 13.1). Ethiopia and Eritrea together have about 46% of all African mules, 69% of horses and 39% of donkeys. The temperate highland climate and cultural tradition are largely responsible for the importance of the horse family in these two countries. There are many donkeys in Egypt, Nigeria and Morocco and Morocco also has 37% of Africa's mules. South Africa, Nigeria, Morocco and (especially in relation to its size) Lesotho, are rich in horses. Mali, Niger and Sudan provide examples of the numerical dominance of donkeys over horses in hot dry areas.

Donkeys were imported in small numbers to tropical Australia until 1910. Stock returns from stations (ranches) in 1920 indicated a total of 655 head, a figure which had increased to 909 by 1932. Donkeys were used particularly in the Victoria River District because of the unsuitability of this area for horses due to Kimberley horse disease (McCool *et al*., 1981). During the 1930s motor vehicles superseded donkeys for transport and many reverted to a feral state. Several hundred were captured in 1942, broken to work and sent to Papua New Guinea to contribute to the war effort. During the 1960s 28 000 donkeys were shot on Victoria River Downs Station as they were then a serious menace to grazing and were the cause of considerable erosion. On some parts of the station their density was 10/km2 and they outnumbered cattle by 3:2. Despite continuous shooting (24 000 were shot from helicopters in Western Australia and a further 15 000 were destroyed by ranchers) donkeys still thrive over much of remote Australia. One aerial survey in 1982 showed 65 755 donkeys and 55 022 'brumbies' (feral horses) on 111 400 km2. The average group size of donkeys was 4.2 although herds of 150200 head were not uncommon.

There was a small annual increase in the world horse population of less than 0.3% in the 1980s and a rather larger one of 1.2% per annum in donkey numbers. Horses in Africa increased by an annual rate of 2.6% in this period while the donkey population increased by only 1.4% per year. It is not clear why the rate of increase in horse numbers is greater in Africa than elsewhere.

Morphology and Anatomy.

The domestic donkey in the tropics is a small hardy animal. It rarely exceeds, and is usually considerably less than, 110 cm at the withers and its weight is usually well under 150 kg. Horses are also generally small, up to about 150 cm at the withers with a maximum weight of 250 kg.

The dominant colour of donkeys is mousy grey although the whole range from black to white is found. Pied donkeys, usually grey and white, are generally rare although not uncommon in some areas. In the Ethiopian Rift Valley, for example, they constitute about 3% of the population. Almost all donkeys have pale rings round the eyes, are pale at the lower muzzle and along the underside of the body, in the inguinal area and on the insides of the legs. The dorsal stripe and shoulder cross are almost universal. Leg stripes are present in varying numbers and intensity on many animals but general striping and eruption of colour along the back stripe are more unusual. A dark brown or blackish patch is present on the base of the ear. The short stiff mane is generally black as is the tuft of hair at the end of the otherwise almost hairless tail.

Horses and mules are much more variable in colour and 'broken' colours or patterns are not unusual. The mane of horses is much more luxuriant than that of the donkey and often the same colour as the body hair. The tail is covered in long hair from the root to the tip.

The most well-known feature of the donkey is the length of its ears. Its head is disproportionately large in relation to its overall size (it has to be helped to swim because of this) and it has a

Table 13.2 Ages at eruption of temporary and permanent teeth in donkeys and horses. (*Source*: Bunger & Hertsch, 1981.)

Teeth type	Position	Species: Donkeys		Horses	
		Deciduous teeth	Permanent teeth	Deciduous teeth	Permanent teeth
Incisors	Central	Present at birth	2.753.25 years	Present at birth	2.503.00 years
	Medial	40 (950) days	3.754.25 years	2842 days	3.503.75 years
	Lateral	9 (614) months	4.755.25 years	69 months	4.504.75 years
Canines			4.255.00 years		4.505.00 years
Premolars	2	}	2.753.00 years	}	2.502.75 years
	3	} Present at birth	2.753.00 years	} Present at birth	3.00 years
	4		3.754.00 years		4.00 years
Molars	1		1.00 year		912 months
	2		2.25 years		2.00 years
	3		3.75 years		3.50 years

large and prominent forehead. The back is longand therefore somewhat weakand the croup is short. With the obvious exception of the size difference the skeleton is similar to that of the horse. The vertebral formula does differ, however, that of the donkey being 7 cervical, 18 thoracic, 5 lumbar, 5 sacral and 17-15 coccygeal vertebrae (Jamdar & Ema, 1982). This C7T18L5S5Ca17-15 configuration differs from the C7T18L6S5Ca21-15 of the horse in that it invariably has one fewer lumbar vertebra and usually several fewer coccygeal vertebrae. Donkey 'long' bones are indeed long in relation to their width in comparison with other equids. 'Chestnuts' (the bony excrescences on the insides of the legs) are absent on the hind legs of donkeys. Teeth morphology in donkeys differs from that of other equids particularly in the lack of the 'horse fold' and in being narrower.

Dentition

Equids have three pairs of incisors, one pair of canines and four pairs of premolars (although the first is extremely small or absent) as temporary, milk or deciduous teeth in each jaw. There are three additional pairs of molars in each jaw in the permanent dentition. The respective deciduous and permanent dental formula are:

Deciduous teeth:

$$2\left(I\frac{3}{3} \quad C\frac{1}{1} \quad P\frac{3(4)}{3(4)}\right) = 28/32$$

Permanent teeth:

$$2\left(I\frac{3}{3} \quad C\frac{1}{1} \quad P\frac{3(4)}{3(4)} \quad M\frac{3}{3}\right) = 40/44$$

Eruption of teeth at all stages is generally delayed in donkeys in comparison to horses (Table 13.2) and is generally about 3 months later for permanent dentition.

Types and Breeds

In the world as a whole many more breeds of horses than donkeys have been described (Table 13.3) but most horse breeds are of temperate origin. In the tropics many fewer breeds of horses are described and there are relatively more breeds of donkey.

Donkeys

Africa is the stronghold of donkeys in the tropics and several attempts have been made to assign African donkeys to breeds. Some 20 have been named but some of these, such as Moroccan and

Table 13.3 Breeds and conservation status of donkeys and horses. (*Source*: Scherf, 1995.)

Species	No. breeds on file	Breeds with population data		Critical or endangered breeds		Breeds at high risk of lossa	
		No.	%	No.	% maintained	No.	%
Donkey	77	24	31	9	0	9	38
Horse	384	277	72	120	20	96	35

a Of those with population data.

Fig. 13.1
A piebald donkey in northern Ethiopia

A Basuto pony in the Lesotho mountains.

Tunisian, often just carry the name of the country where they are found. Some country types have been further divided into varieties as in the Egyptian which includes the Baladi of Lower Egypt, the Saidi of Upper Egypt and the Hassawi which is a white-coloured saddle type.

Many donkeys show variations in colouring and the amount of striping. In some areas, notably parts of Ethiopia (Fig. 13.1) and western Burkina Faso, a comparatively large proportion of donkeys is black and white. With few exceptions, however, there is little morphological separation in the ubiquitous and all-purpose small grey donkey, that is rarely much higher than 100 cm at the withers and usually weighs about 125 kg. It is nonetheless certain that distinct 'populations' have evolved in response to local selection pressure and stresses (see Chapter 5). These should be characterized to identify the best performing and best adapted strains and to recognize their qualities.

Exceptions to the general grey African donkey are mainly found in East and Northeast Africa. The Masai donkey is often brown or reddish brown. In Sudan a larger riding type (cf Fig. 5.1), standing 112120 cm at the withers and weighing 140 kg and that is almost never used as a pack animal, has evolved. Sudanese Riding donkeys possibly result from crossing with the 'Arab', 'Egyptian' or 'Syrian' donkey. This animal, also known as the Rifa'i or Rif in parts of Sudan and Eritrea, is much larger than the African grey, averaging 123 cm at the withers and weighing 160 kg or more. A small number of 'Muscat' donkeys in coastal Tanzania are of this larger type. Syrian donkeys are usually white and are essentially found in urban areas where they generally receive slightly better nourishment than their smaller relations. The larger donkey is used almost uniquely as a riding animal85% of Syrian donkeys in a Sudan survey were ridden whereas only 42% of grey donkeys occupied this role (Wilson, 1978a).

Small donkeys are the rule in much of the Arabian Peninsula where the Qaramani is found in northern Yemen.

In Nepal, small Tibetan (8090 cm withers height) and larger Indian (110 cm) donkeys are kept in small numbers in parts of the Terai low-lands close to the Indian border, the mid Hills region and in the Mustang area of the northwest Mountains area. Tibetan donkeys are usually dark brown in colour whereas Indian donkeys are light grey to almost white as, indeed, they are in their country of origin. Donkeys are used only as pack animals, the Tibetan usually being loaded with about 50 kg and the Indian with 6080 kg. In India itself, however, there appear to be two distinct types of donkey, one being the larger one that is used in Nepal, the other a much smaller type of between 81 and 94 cm at the withers. The Puttalam Buruwa donkey of Sri Lanka is an endangered breed.

The Pêga donkey of Minas Gerais State in northern Brazil is usually roan or dark grey. It probably originates from large Italian and Iberian types and smaller Egyptian ones imported in the early nineteenth century. A herdbook and breed society were established for this donkey in 1949. It is sometimes also known as the 'lagoa dourada' (manacles) after the brand of its original breeder.

Horses

Many horses in the tropics are descended, near or far, from Arab stock and from all of the three main strainsthe Keheilan, Maneghi and Saglawi.

Some 3040 'breeds' of horses have been listed for Africa. There has, indeed, been more differentiation in horses than in donkeys. A great deal of Arab blood has been introduced over the centuries. The Barb from the Maghreb and North Africa and the Dongola from northeast Sudan and western Eritrea are well-known and clearly differentiated types. Both have been crossed with and absorbed, or been absorbed by, local breeds in their areas of expansion. Barb horses have influenced equine breeding over a wide area from Spain to the United States, where there is a breed society.

Western Sudan and Kirdiknown in French as Logoneare smaller Sahelian horses of northern Sudan and southwest Chad. Basuto Ponies in Lesotho originated from the Boer or Cape Horse (itself a mixture of Javanese, Arab and Andalusian stock) in about 1825. Basotho tribesmen got foundation stock through trade, barter, wage labour and theft, and quickly developed an affinity for horses. Basuto ponies (Fig. 13.1) rarely exceed 135 cm at the withers; they have thickset bodies, short legs and pasterns, and compact hooves confer stamina, endurance and agility. They are docile and intelligent. In the twentieth century they have suffered from crossing with Arab and Thoroughbred stock and lost much of their adaptation to the harsh Lesotho environment. Steps are now being taken to redress the balance. The Cape horse was itself almost extinct but has been 'revived' from 'suitable' breeds and a herdbook established for the recreated horse in 1957. The Boer was also the origin of the Calvinia, developed by crossing with Thoroughbred, Hackney and Cleveland Bay stock.

Horses were probably imported to the major part of South Asia from Western Asia and Turkey. There are six important horse breeds in India. Two of these, the Kathiawari (also known as the Kutchi) and the Marwari (or Mallani) are probably of Arab descent, while the Manipuri, Bhutia, Spiti and Chumanti are pony types. All the breed names are related to the present or original locations of the breeds. The Kathiawari is considered the best Indian breed, is 120150 cm at the withers, and is variable in colour; it has well muscled quarters and is a fast mover. The Marwari is slightly bigger than the Kathiawari, usually bay, chestnut or cream in colour, sturdily built and fast. The Bhutia takes its name from the tribe which breeds it; it averages 130 cm at the withers and is a sturdy riding and pack animal with a thick muscular neck, a broad chest, strong back and round muscular quarters. The Spiti and Chumanti are similar, both adapted to the cold hill climates, and grey or dun in colour with some bay and black animals. The Manipuri is about 140 cm at the withers and is favoured as a polo or racing pony but is also used as a pack animal. In Pakistan the Baluchi is a light horse with turned-in ears and the Hirzai, which is now rare, is descended from Arab stock. The Rajshahi pony is found in Bangladesh.

The northern and western districts of Nepal are traditional horse and pony breeding areas (Pradhan *et al*., 1991) but it is possible to see some almost everywhere. Ponies in the northwest are generally known as Bhotia (= Tibetan) and are variously used as riding and pack animals. They are said to be similar to Tibetan ponies although less broad (Mason, 1996) but there has undoubtedly been considerable crossing with Indian and Pakistani horses over the centuries. Three main types are recognized. The Tattu is the smallest, rarely exceeding 120 cm at the withers and often being as small as 107 cm. It is normally only used for pack and can carry 6080 kg all day up and down the very steep terrain of the higher mountainous areas to which it is confined. The Chyanta is larger, about 128 cm, and used mainly for riding on steep mountain slopes where its short stepping gait is well adapted to the terrain. The Tanghan is a yet larger riding variety, up to 136 cm, with a normal gait. The colour is usually bay but white ponies with unpigmented skin are not uncommon. Mountain ponies have long shaggy winter coats in contrast to a generally short and moderately fine summer one. Horses in the southern lowlands are known as Terai ponies, a small (110120 cm) and very lightly built animal. It is sometimes considered to be a true pituitary dwarf (Epstein, 1977). The short fine hair is usually bay coloured but there are some white ponies with a dark pigmented skin.

Ponies of the Southeast Asia breed group are widespread from Myanmar in the west to Japan in the east and from southern China in the north to Indonesia in the south. The group probably originated form Mongolian ponies crossed with Arab types (Mason, 1996). These are generally small hardy animals used for pack, carting, traction and riding. The group includes the Guanxi, Guizhou, Jianchang and Lijiang types from southern China; all of these are used in the breeding of mules and hinnies (Fig. 13.2). Other

Fig. 13.2
A hinny and a mule in Jianchang County, Yunnan Province, China

A group of mules, their horse dams and donkey sire in Botswana.

Fig. 13.3
A Vietnamese pony of the Southeast Asia group near
Dong Hoi in central Vietnam.

representative types in this group include the Batak from Sumatra, the Cambodian which is similar to the Thai and Vietnamese which is sometimes known as Annamese (Fig. 13.3), the Kumingan from West Java, the Macassar from Sulawesi, the Philippine, the Shan from Myanmar, the Sumbawa from Indonesia and the Timor. The tiny (100 cm, 80100 kg) Baise pony of Yunnan Province in southwest China is an endangered breed.

All horses in South America are originally descended from Spanish imports at the beginning of the fifteenth century. Most are part of a breed group known as Criollo (native) which is a term also applied to cattle and other domestic stock. There are Criollo types in Argentina, Bolivia, Chile, Mexico, Peru (including a smaller distinct type known as the Chola, the larger Costeña from the coastal region and the Morochuca from the mountains). Recognized distinct breeds in Latin America include Crioulo from southern Brazil, the Campolino from Minas Gerais, named after its original breeder and having infusions of various types of northern European and American blood, and the Mangalarga also from Minas Gerais, the latter two having breed societies. The Bagual and Puno ponies are feral types from Argentina and Peru. The tiny Falabella pony of Argentina was developed from the Shetland but is now at high risk of extinction.

Mules and Other Hybrids

An important function of the donkey is its role as one progenitor of the mule and the hinny. With a total world population in excess of 15 million, these hybrids are also important as providers of transport and draught power in many tropical countries. Crosses between donkey males and horse females have been practised from an early stage of domestication, these being known as mules in English. Mules (Fig. 13.2) are bigger and stronger than donkeys and bring to the cross some of their hardiness and disease-resistant traits so they can work in more difficult situations than horses. The reverse cross from a horse male and donkey female, known as the hinny, is much less common. Hinnies are also smaller than mules reflecting the relative sizes of their female parents. Mature mules and hinnies are almost always infertile because of the differences in the chromosome numbers of their parents but there are rare cases of mules or hinnies giving birth, usually with a donkey as sire. The karyotype of thoroughly investigated foals born as offspring of hybrids sometimes shows a whole set of horse chromosomes, a mixture of horse and donkey chromosomes (Chandley, 1991) or purely donkey chromosomes (Benirschke *et al*., 1964).

Most mules in the tropics are the result of local parents on both sides. Exotic parents of either species are sometimes used especially for breeding mules. In Algeria, Poitou donkeys from France and Catalans from Spain have been used for mule production. In Australia a Spanish donkey was imported to Victoria River Downs to produce mules in 1907. There is evidence of this and probably similar cases in the presence of large black donkeys as much as 150 cm at the withers in the feral population (McCool *et al*., 1981).

Fertile matings between all possible combinations of the equid species (Table 13.4) have been made experimentally, often in zoos in furtherance of the study of the genetic transmission of chromosomes. The developing embryos of these often die within a few days of conception because of the variations in chromosome numbers. Those that survive as crosses of horses or don-

Table 13.4 Domestic and wild species of the genus *Equus*.

Species and subspecies	Common name	Chromosome numbera and notes
caballus	Horse	64
Przewalski	Przewalski's horse	66; extinct in wild, safe in zoos
caballus Gmelini	Tarpan	Extinct in Poland
hemionus	Kulan, onager	56; SyriaManchuria
hemionus khur	Indian wild ass	PakistanIndia
hemionus hemihippus	Syrian wild ass	Extinct in early twentieth century
kiang	Kiang	Tibet, Sikkim, Ladakh
asinus	Donkey	62
asinus africanus	Nubian wild ass	62; extinct
asinus somaliensis	Somali wild ass	62; almost extinct
greyvi	Greyvi's zebra	Ethiopia, Somalia, north Kenya
burchelli	Burchell's zebra	Extinct in Namibia
zebra		Angola, Namibia, South Africa
quagga	Quagga	Extinct in Namibia

a 'zebra' chromosome number varies from 32 to 46.

keys with various zebra species are usually referred to as zebroids but distinctive namesassbra, zebrule, zebrinny, zebryle, zebret-have been coined for particular crosses.

As for horsedonkey hybrids almost all surviving hybrids between different equine species are sterile. This is primarily due to their abnormal chromosome complement which is usually intermediate between the diploid numbers of their parents (Table 13.4). Sterility in males is due to a failure of spermatogenesis which probably occurs in the meiotic prophase. There appears to be no impairment of androgen or oestrogen production.

Genetic Modification

As well as centuries-long gradual modification of genotypes by traditional owners, there were concentrated formal efforts at breed improvement during the colonial era. The spread of the Barb and Dongola horses from Northern and Eastern Africa to West Africa and intermingling and 'degeneration' of these with pre-existing stock to form a multiplicity of named but ill-defined and often phenotypically similar types is an example of long-term modification. Spread of the larger Syrian donkey through Northeast Africa is another example.

One early formal scheme was in Sudan (Wilson, 1978b) but there were remarkably similar attempts in Mali and elsewhere. These schemes, sometimes thinly disguised as improvement of local stock, were often covertly or even overtly designed to provide transport and riding animals at low cost for the administration and military of the colonial power. The Sudan scheme attempted to modify the Western Sudan pony to make it suitable for military use in other parts of the British Empire. Before 1920, mares were served by Arab stallions from all the major lines but improvement, if it occurred, was slow. In spite of efforts to involve local people through the show ring and by cash incentives and other prizes, they were reluctant to take part in the programme. Few halfbreds reached the required military standard, nor did many of the back crosses to the Arab. Some British aristocratic philanthropy later allowed a few Thoroughbreds (they were not, of course, the very best and had usually failed spectacularly in their racing careers) to be imported. This achieved little more success than Arab blood and it seemed at Independence in 1956 that the scheme would fold, leaving little evidence of its 40 years' existence. Surprisingly, it took on a new lease of life at this stage, with Thoroughbreds imported from France and later from Kenya. Local notables, free from the restraint of supplying offspring to the administration, now used them for their own prestige on the racecourses of Nyala, El Obeid and Khartoum. The lesson is clear improvement programmes are only likely to succeed if there is obvious benefit to the participants.

Basuto ponies suffered a fate similar to that of the Western Sudan pony. Numbers peaked during the 1870s, but 20 000 (naturally the best animals) were then bought by the British for the Boer War. Drought, severe winters and diseases such as glanders, strangles and African Horse Sickness also contributed to declining numbers and quality. First attempts to increase numbers used Arab stallions. Thoroughbreds were used from 1906 to 1932 but this was later realized to be a mistake. Early programmes also lacked continuity and good organization.

A programme set up for Basuto ponies in 1980 (McCormack, 1991) aims to maintain it as a suitable mode of rural transport, develop and exploit local and export markets, and improve production through extension advice. A National Stud Farm has been established to produce elite animals for breeding and riding. Selection criteria include pedigree, uniformity of type, conformation, hardiness, fertility, and tripling ability. Tripling is a fifth and comfortable riding gait in addition to the usual walk, trot, canter and gallop. Stallions potentially of the required standard are sent to Livestock Improvement Centres for a trial period. Mare camps, operated by villagers on set-aside communal land, are another approach to mating only by improved stallions. The project continues but an important preliminary conclusion is that long-term commitment by the authorities and the farmers is required for its ultimate success.

Much less attention has been paid to genetic manipulation of donkeys. One scheme in Mali used Poitou (a breed itself now critically endangered) jacks from France on local jennies. It failed largely through lack of farmer interest and possibly because the crossbred offspring were much bigger, and therefore needed more feed and attention, than the local type.

Adaptive Physiology

Donkeys, on which among the equids most physiological work in the tropics has been done, more closely approach the camel in survival ability in hot and dry areas than any other domestic species. Deep body temperature fluctuates from the norm of 36.4°C down to 35.0°C and up to 39.3°C. Above the latter temperature severe signs of stress are shown and signs of approaching explosive heat death may be shown (Schmidt-Nielsen, 1964). Water loss by donkeys is still, however, two to four times that of camels under comparable conditions. The main reasons for the difference are not only the narrower limits of temperature fluctuation but also relate to less well-developed behavioural adaptations to reducing heat gain.

Donkeys (as other equids) dissipate heat mainly by sweating and sweat glands are present over the whole body. Sweating rates of 145 g water/m2 body area/hour occur at high ambient temperatures and respiration rates can rise from the normal 1430 to as high as 130 breaths per minute (Maloiy, 1971). The main areas of sweating in all the Equidae are around the ears, in the anal and inguinal regions, by the teats and on the chest. Normal heart beat rates of 3845/minute are not much affected by heat. At temperatures below 10°C, donkeys shiver to generate heat and erect the body hair as a barrier and the metabolic rate increases by 20% compared to that in the thermal neutral zone of 2232°C.

In fasting donkeys the respiration rate first drops and then increases but the heart rate falls continuously to about 32 beats per minute after 48 hours (Yousef & Dill, 1969a, 1969b). Both respiration and heart rates increase after fasting.

Faeces are the second major source of water loss. Dehydrated donkeys reduce faecal water content from 68 to 61%. Faecal dry matter output is also reduced by 40% which conserves more water. Prolonged water deprivation reduces dry matter feed intake from about 3.1% of liveweight to 2.2%. Urine output is low even in fully hydrated donkeys and averages about 0.71.2 litres/day. Donkey kidneys cannot excrete highly concentrated urine, the maximum appearing to be about 1550 mOsm/kg water with a urea content of 300410 mM. Donkeys will not usually accept drinking water with a sodium content of more than 1.0%. Body chloride concentrations rapidly return to normal on rehydration indicating that sweat is relatively free of chlorides.

Donkeys drink about 3.5% of liveweight daily as water but this may rise to 12.0% under heat stress. Under heat stress and when deprived of water, total daily water loss amounts to about 2.5% of liveweight. Appetite begins to fail at 2022% weight loss but donkeys can recover from a total loss of 30% of body weight. Water is drunk very rapidly when it becomes available after dehydration and 2430 litres of water can be drunk in 25 minutes. Up to 98% of the original liveweight loss is recovered in 10 minutes without harmful effects (Fig. 13.4).

Water is first lost from intracellular fluid, then extracellular fluid and finally from blood plasma. In donkeys that lost 18% of body weight, intracellular fluid was reduced to 68% of the original volume, extracellular to 86% and plasma to 93% (Yousef *et al*., 1970). Blood liquidity is thus maintained under heat stress and dehydration and circulatory problems do not occur. Plasma volume is probably maintained by control of capillary wall permeability and ion and protein fraction movement.

Reproduction and Breeding

Males.

Free-living equine malesand many tropical horses and donkeys are essentially free-living in the reproductive senseare territorial. For practical herding purposes this does not create problems because other males are not excluded and dominance is used to achieve reproductive success. Domestic horses, unlike some monogamous *Equus* species, acquire small harems and protect these against other males and external danger. Females, which are gregarious to a greater or lesser extent, come to a male's territory to be mated. Female group size depends on access to feed resources and nutritional status. From the male's point of view, better fed females assure

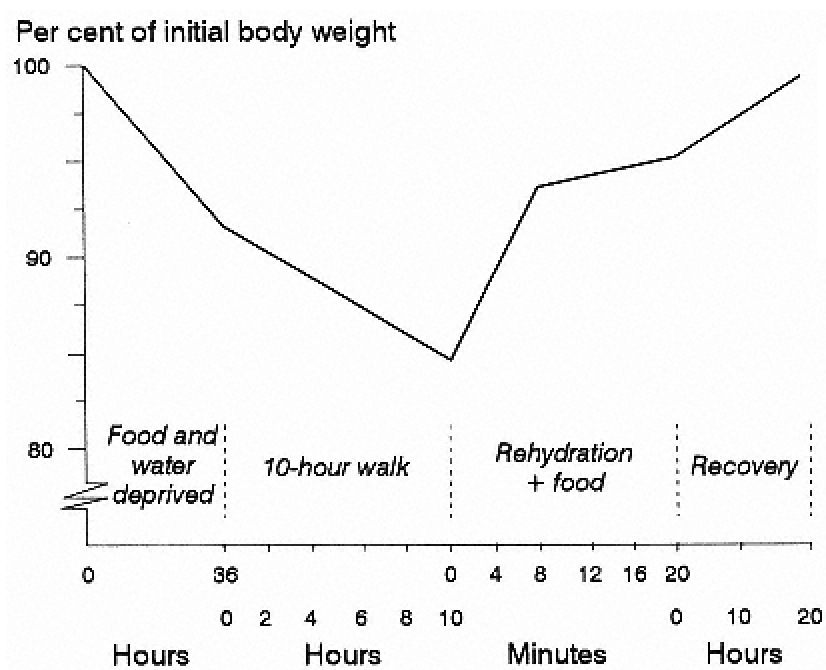

Fig. 13.4
The cycle of events in dehydration and rehydration of the donkey.
(Source: Yousef & Dill, 1969a.)

greater success as they group more closely, show stronger signs of oestrus and are more willing to be mated. With these conditions, males require only a short breeding period before returning to the matter of their own survival and betterment through the dominance hierarchy.

Male donkeys and horses achieve sexual maturity, defined as the presence of sperm in epididymal smears, at varying ages but usually during the second year. At sexual maturity the semen of donkeys is more milky and turbid than that of the horse and is brownish yellow in colour. An average donkey ejaculation is about 50 ml and contains about 24 × 109 spermatozoa. The pH is slightly alkaline. Nutrition, as in other species, is probably important in maturity, as in a feral population in northern Australia only 43% of 3-year-old jacks were mature in a high density area (3.3 donkeys/km2) in contrast to 100% in a low density area (1.7 head/km2) (McCool *et al*., 1981).

Females

Age at puberty in females varies from as young as 1 to more than 2 years but first mating does not usually take place until at least 2.5 years and 34 years is more usual. Two of five female donkeys aged between 5 and 11 months were found to be cycling in Australia (McCool *et al*., 1981). In temperate and subtropical latitudes equines are seasonally polyoestrus, the breeding period coinciding with the late spring and summer, but there is some breeding all year round in the tropics.

Empirical observations in Ethiopia and Sudan are consistent with the foregoing. Births in donkeys and horses occurred all the year round (Wilson, 1978a, 1991). Donkey births none the less showed a marked seasonality in Ethiopia, with 49% of all births being in JuneAugust and another 30% in MarchApril, the peaks coinciding with conception the previous year during the 'short' and 'long' rainy seasons. In India foaling was highest in May (Kohli *et al*., 1957) coinciding with conception at the beginning of the monsoon the previous year but breeding does occur all the year round. The onager, which does not interbreed with the domestic donkey, is apparently in season only in AugustOctober. In Australian feral donkeys (McCool *et al*., 1981) more than 85% of conceptions were in the summer months of SeptemberJanuary with no conceptions at all in MayJune and very few in February, March and July.

The oestrous cycle is normally in the range 2125 days with extremes of 19 and 28 days. Oestrus usually lasts 27 days although it may be as long as 10 days in India in donkeys. The 'foal' heat usually starts at 78 days after parturition in horses but at 1718 days in donkeys in the range 669 days. Diarrhoea in foals, which appears at about 10 days, is probably associated with the return to oestrus (and thus the presence of hormones in the milk) of their dams. Behaviour at oestrus may be subdued if jacks or stallions are absent although females together may bite and kick each other. Signs of oestrus are mouth-champing, salivary dribbling, clitoral winking, tail raising and frequent urination. Teaser animals can help to improve reproductive performance.

Ovulation is spontaneous and occurs 56 days after the onset of oestrus with eggs normally being shed only once although some females ovulate two or three times. Some donkeys show signs of oestrus and will accept service even when pregnant. The corpus luteum declines early in pregnancy (Fig. 13.5) and gonadotropins appear in the blood serum (Asdell, 1965).

Gestation in the donkey is 372375 days in India and Brazil (Jordão *et al*., 1951) within a range of 346393 days. The mean is longer than the horse, which averages 336337 days. Female foals are usually carried for a shorter period than male ones and there is some evidence to suggest that donkey mares in foal to horse stallions have a gestation period 812 days shorter than normal. As in other species of livestock, nutritional status greatly affects conception rates. In dry areas it could be expected that horses would have higher individual annual reproductive rates than donkeys because a shorter gestation period allows them to foal earlier in the next rains and maintain or gain body condition during the time when feed is most abundant and of high quality.

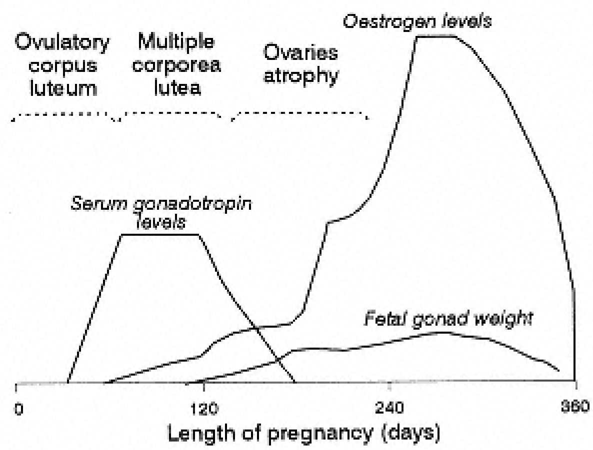

Fig. 13.5
The reproductive cycle in the horse.
(Source: Asdell, 1965.)

Higher mortality rates and the expense of keeping horses in many areas probably account for their smaller numbers in spite of potentially better reproductive performance.

First parturition is usually somewhat delayed in relation to puberty being attained. In Australian feral donkeys only one of nine females aged 23 years had given birth but all older animals had already foaled. In a sample of Tuareg and Fulani donkeys in Niger some donkeys had already given birth while still having only temporary incisors (<30 months) but most females with first foals had erupted two pairs of permanent incisors and were therefore about 3.5 years old (Wilson & Wagenaar, 1983). In a sample of 128 donkeys in India the mean and standard deviation of age at first foaling was 59.7 ± 1.09 months (Kohli *et al*., 1957) but in the traditional small-scale system the donkey is said to foal first at 2.53 years.

The pregnancy rate in a Brazilian study averaged 57.1% over an 11-year period varying from 23.8 to 85.7%. The mean rate was 47.5% in 35-year-olds and 61.5% in donkeys 911 years old. In the Australian feral population 64% of females were pregnant and 17% of these had foals at foot. In Sudan the estimated foaling rate was about 70% but in Niger was probably just over 40%. If rates of more than 50% are to be achieved by both donkeys and horses a considerable proportion has to conceive on the foal heat.

Horses and donkeys may have a useful reproductive life in excess of 20 years.

Fertility in Mules and Hinnies

Donkeyhorse and horsedonkey crosses are usually sterile and reports of fertile hybrids have normally been treated with suspicion. Chromosome analysis and biochemical studies of blood serum cholinesterase have now revealed some very rare cases of genuine fertility in mules. The potential to produce further crosses from fertile backcrosses could give rise to animals with economic value even better than those possessed by the mule and hinny.

Pregnancy Diagnosis

Horses were the animals in which pregnancy diagnosis other than by physical examination was first developed. The use of pregnant mare serum gonadotropin (PMSG) is widespread for this purpose. The Cuboni test was an early and sometimes still used method for pregnancy diagnosis in horse mares. Unfortunately most biological tests for pregnancy used for horse mares give unsatisfactory or even misleading results in donkeys. This is probably due to reduced secretion of gonadotropins in the urine. There also appears to be reduced steroid secretion by horse mares in foal to donkey jacks. Pregnancy diagnosis in donkeys might therefore be better performed by physical methods. For both horses and donkeys, however, the use of ultrasound scanning is very simple and reliable from a very early stage of pregnancy and can be expected to assume increasing importance in the tropics.

Nutrition

Biochemistry and Physiology

Equines are hind-gut fermenters and most digestion takes place in the caecum and the small intestine. The Bovidae and the Camelidae are fore-gut fermenters with most digestion taking place in the rumen. It is generally accepted that ruminantand in particular bovidevolutionary success is the consequence of a highly efficient digestive system.

Equids are far less differentiated than the Bovidae, comprising only one extant genus (see 'Origins and ancestry' earlier in this chapter). They have nevertheless survived competition, probably because they can extract nutrients from the very coarsest forages faster than can bovids but to do this they have to ingest rather large amounts in relation to their size. Dry matter intake is therefore high compared with other large herbivores and is about 3.1% of liveweight (Maloiy, 1973). The ability to maintain appetite, especially in the case of donkeys, in spite of dehydration is quite possibly an adaptation to this type of food utilization. The ruminant digestive system, however, allows these animals access to nutrients protected by plant secondary metabolites and antidigestion factors and which equids cannot use. It is probably because of this antidigestion effect that equids in general eat mainly grasses whereas ruminants make more use of dicotyledonous plants.

Physiological differences between the activities of the gastrointestinal tract of donkeys and that of ruminants are not really apparent in spite of the obvious anatomical differences (Maloiy & Clemens, 1980). The dry matter consistency of fore-gut contents, the addition of fluids to the contents of the small intestines and the drying of the gut contents rearwards from the caecum to the rectum are all similar. Organic acid concentrations in the upper (cranial) part of the equid stomach appear similar to those found in the rumen of ruminants although the volume of the gut fill is much smaller. In equids the relative capacity of the stomach is 14 and that of the caecum and colon is about 80 whereas in ruminants the reverse situation prevails. Microbial digestion in the horse and donkey occurs principally in the caecum and colon while in ruminants it takes place in the rumen. The 'stomach' of ruminants and the large intestine of the Equidae are therefore functionally similar.

Dehydration in the thermo-neutral zone of the donkey and at high ambient temperatures of 40°C depresses feed intake to some extent but apparently increases dry matter digestibility. Intermittent changes in temperature such as the great diurnal variation in deserts do not depress appetite providing water is not limited (Maloiy, 1973) and donkeys seem very well adapted to adverse nutritional conditions (Izraely *et al*., 1989).

Because they lack a rumen, and thus a large storage capacity, horses and donkeys need more frequent access to food than ruminants. When given the opportunity, horses and donkeys eat many small meals all day and night and try to maintain a high level of gut fill. Free-ranging horses spend as much as 70% of total time in feeding, spreading this activity rather equally over the whole period (equines sleep in general less than 4 hours per day). This is in contrast to the concentrated, mostly daylight, feeding sessions of ruminants, that are followed by long periods of rumination. Total foraging time by ruminants is about half that of the Equidae when both are herded together or present in the same habitat. Whenever possible, therefore, horses and donkeys must be allowed time to feed or be provided with feed to suit this imperative. This general axiom does not apply to suckling foals, which obtain all their feed requirements from their dams' milk until about 8 weeks of age. After this, however, they spend more and more time feeding; the contribution of milk to energy intake drops to about 40% by 6 months and is reduced very sharply afterwards.

Studies comparing donkeys and sheep show that the former digest cell wall components (including dry matter, neutral-detergent fibre, acid-detergent fibre, cellulose and lignin) of roughages less efficiently (Butterworth *et al*., 1988). This is consistent with rapid feeding rates and therefore faster rates of passage through the gut of the feed eaten. Dry matter (DM) intake was almost 30% higher by donkeys, which ate 2.42.9 kg DM/100 kg liveweight or 7396 g DM/kg metabolic weight. Because of this high consumption rate, overall digestible matter intake was 20% higher in donkeys than in the ruminants. Horse dry matter intake in relation to body weight is similar to that of donkeys.

Feed Preferences

Horses and donkeys are bulk and roughage feeders (van Soest, 1982) that consume mainly grasses and other monocotyledons including sedges, rushes and reeds. Under some conditions, however, they tend towards intermediate feeding strategies and select leaves, fruits and flowers from a variety of plant groups. The diet quality selected by donkeys, however, is closer to that of cattle than to the other ruminants or the camel. In both dry and wet seasons cattle are the least selective of feeders, their diets being lowest in crude protein and highest in fibre. They are followed by donkeys in these parameters, then by sheep. Goats and camels select better quality diets of higher protein and lower crude fibre content.

Under ideal grazing conditions, the range of plant species eaten by equids is rather narrow but they select plant parts of higher quality. Under less than ideal conditions, however, they are much less selective and because of this the protein content of their feed can be 80% less in a dry than in a wet season compared to 43% less for camels and goats, 55% for sheep and 68% for cattle (Coppock *et al*., 1982). Equines also tend to graze longer and on coarser vegetation than do cattle and sheep. Dietary overlap between cattle and horses, measured as the product of the time spent in the same habitat and the number of species eaten in common, ranges from 55 to 70% (Schwartz, 1988). Donkey feed preferences also bring them into competition with cattle (Rutagwenda *et al*., 1990). Donkeycattle dietary overlap in African grazing systems is higher than for all other combinations of domestic species (Table 13.5). Competition between all pairs is reduced in the green season when feed is more plentiful. The worst effects of competition are reduced to some extent (Fig. 13.6) by donkeys grazing slightly higher above the ground than cattle and by the limited number of species they eat (Coppock *et al*., 1988). In many tropical grazing systems, feed quality is better farther from the ground and may confer some marginal benefits to equid grazing.

Most equines in the tropics undoubtedly get most of their nutrients from natural pastures. In India working donkeys may be provided with about 1 kg of wheat straw and 2 kg of crushed grains or gram or about 4.5 kg of 'bhoosa' (legume haulm) with varying amounts of cereal grain. In Ethiopia and elsewhere in Africa two or three handfuls of small and broken grain or bran may be provided. Urban donkeys and horses are the main exception to this paradigm and are the basis of a considerable trade in natural bush hay and legume haulms; where horses are kept as prestige animals they are fed considerable amounts of grain and other concentrate feeds even in traditional farming systems.

Feeding Behaviour

In much of the tropics donkeys are ubiquitous beasts of burden and horses and mules are used for riding or transport. All three species are thus

Table 13.5 Extent of dietary overlap between species pairs during dry and wet seasons in semi-arid savanna in Kenya. (*Source*: Rutagwenda *et al*., 1990.)

Species	Species and season							
	Cattle		Donkeys		Sheep		Goats	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Camels	3.3	8.5	18.9	7.2	30.5	14.2	47.5	12.4
Cattle			73.2	50.5	49.6	20.1	12.6	23.3
Donkeys					59.6	20.4	29.7	13.8
Sheep							36.6	43.0

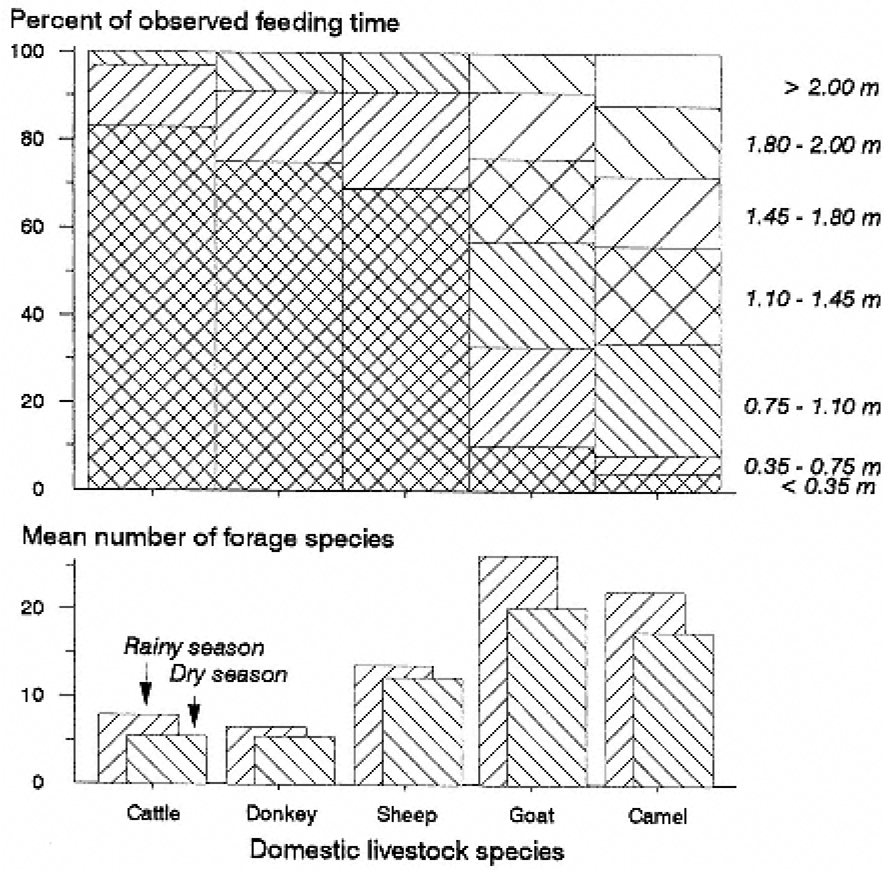

Fig. 13.6
Feeding heights and number of forage species selected by donkeys, ruminants and camels in semi-arid thornbush savanna in Kenya.
(Source: Schwartz, 1988.)

subject to a daily timetable that differs markedly from that of ruminants. In Ethiopia donkeys spend 53% of daylight hours on the move in the service of their owners and only 36% grazing. Horses spend 45% moving and 15% grazing and mules 58% moving and 10% grazing. Horses and mules spend 40% and 31% respectively of daylight restingwaiting for their ownerswhen they may be fed roughage or grain. All equids suffer from restricted feeding periods, however, a deficiency they must make up at night or risk severe malnutrition.

Although donkeys are tolerant of long periods of thirst they are usually watered every day or at least once every 2 days. Their role as transporters of water for their owners is an advantage in this respect. It also means they spend considerable amounts of time travelling, particularly in the late dry season (Fig. 13.7). Unlike most species, donkeys are often allowed to roam freely at night and total active time may approach 24 hours per day. This contrasts with the figure for ruminants which is usually in the region of 1015 hours.

Health

Horses and donkeys differ in resistance to, and tolerance of, many diseases but show similar susceptibility to others. Part of the donkey's ability to survive in harsh environments arises from its immunity to many problems associated with aridity and heat. The horse, which is better adapted to cooler and moister climates, has diffi-

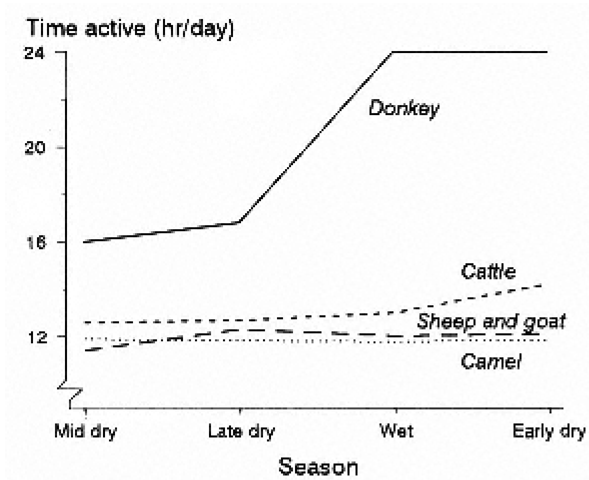

Fig. 13.7
Activity patterns for free-ranging livestock in south Turkana, Kenya.
(Source: Coppock *et al*., 1988.)

culty in these environments because of high rates of water, and thus of energy, use.

Virus Diseases.

African Horse Sickness is prevalent in Africa and is a major problem in horses. Horse Sickness was present in 13 African countries in 1990, from South Africa in the south to Morocco in the north and from Cape Verde in the west to Ethiopia in the east, but was probably also present in Somalia. It also occurs in West Asia at least as far east as Iran. Vaccination is usually effective in horses although the immune response is sometimes inadequate and the vaccine is not always readily available. Persistence of the disease is probably assisted by the maintenance of a reservoir in donkey populations which, at least clinically, are not affected.

Equine infectious anaemia and equine influenza are other widespread virus diseases, mainly of horses. There was a major outbreak of the latter in India in 1987, prior to which there had been no serological or virological studies on the disease and little suspicion that it was a problem (Uppal, 1991). The disease manifested itself as a respiratory problem accompanied by coughing, fever, nasal discharge, laboured breathing, pneumonia and weakness. The disease was found in six states in the northern part of the country and all classes of horses and donkeys were affected. Secondary complications, including strangles, pulmonary emphysema and asthmatic conditions, developed in animals that were not given sufficient rest, kept in poor hygienic conditions or received inadequate therapy.

Horses and donkeys can be carriers of and are affected by rabies and care should always be taken when handling animals that act out of character. Other viral diseases that affect all three equines include the venereal disease equine herpes and papillomaviruses.

Bacterial Diseases

Among bacterial diseases, vaccination against anthrax is effective in control but reactions to the vaccine, especially in donkeys, can be severe. Epizootic lymphangitis is a common bacterial disease of horses that also affects donkeys but the latter are much less susceptible. Donkeys suffer from an acute form of glanders whereas the disease is much more chronic in horses. Darfur and Kordofan in Sudan are major foci of glanders in horses.

Trypanosomosis

The horse is very susceptible to trypanosomosis, the insect-borne type being known as surra in equids. Donkeys are not immune and often carry chronic infections, especially of *Trypanosoma evansi*, without exhibiting clinical symptoms and act as reservoirs for reinfection of other livestock, especially camels. *T. evansi*, with no part of its life cycle in the fly vector, is usually transmitted mechanically by biting flies of the Tabanidae family. The main tsetse-transmitted trypanosomes of Equidae are *T. brucei* (the most pathogenic), *T. congolense* and *T. vivax*. Treatment by drugs can be effective in curing trypanosomosis if dosage regimes are correct. Suramin can be used as a curative, especially of *T. evansi*, but should not be used as a prophylactic as there is a real risk of resistance developing in the parasite. Isometamidium can be used against most

Trypanosoma species but is not especially effective against *T. evansi* unless given at very high rates which the animal may not tolerate well. A new arsenical compound known as cymelarsan is an effective control of *T. evansi* in camels (Zweygarth *et al*., 1990) and its use may be extended to horses and donkeys in the future.

A peculiar form of trypanosomosis, restricted to equines and the common name of which is dourine, is caused by *T. equiperdum*. Dourine is sexually transmitted and its control is therefore, in theory, simpler than forms carried by insect vectors. It has, in fact, been eradicated from most countries but persists in many developing tropical countries. Control is by identification in sera of infected animals and their subsequent sterilization or slaughter. Drug treatment is not satisfactory as elimination of the infection is not certain and treated animals may become carriers.

Internal Parasites

The poor nutrition and heavy work to which horses and donkeys are subject in the tropics, coupled with common grazing, are ideal conditions for the proliferation of internal parasites. Almost all animals are infected with a range of parasites and single parasitism is rare (Eykser & Pandey, 1989). Strongyles in the alimentary tract are the most prevalent and the stomach, large intestine and small intestine can all harbour parasites. Many parasites infecting equids also infect other species of livestock and cross-infection is common. On the other hand equids have species of worms which affect only them and there are species which are peculiar to each of horses and donkeys.

In addition to alimentary tract helminths, Equidae suffer from many other internal parasites. The donkey is the natural host of the lungworm *Dictyocaulus arnfeldi* and this worm is almost universally found in them. Donkeys in Ethiopia can also be infected by the liver fluke *Fasciola hepatica*, although this snail-borne parasite does not apparently infect equines in Zimbabwe and Morocco (Pandey, 1981). Because of their close, if sometimes casual, connection with man, Equidae act as transmitters of some zoonoses including filarial worms of the genus *Onchocerca* and the hydatid cyst *Echinococcus granulosus* which is almost universally present in donkeys. In India larvae of the bot fly *Gasterophilus intestinalis* are present in the stomachs of a majority of donkeys.

There has been an increasing number of drugs available against internal and external (and often against both at the same time) parasites in recent years. Strategic dosing regimes for various environments have been developed for both horses and donkeys, these varying with species of parasite present, level of infection and local climatic regime. Many must be used with care, however, as horses and donkeys may show strong adverse reactions to the common drugs used for other species of domestic animals. The high cost of drug treatment also mitigates against regular use by large proportions of the animal-owning community in much of the tropics.

Other Health Problems

Many health problems in equines are mechanical in nature. They result from mistreatment or from badly fitting harnesses and take the form of sores, ulcers and broken or misshaped limbs. These problems can be overcome by better management and creation of awareness of their nature by publicity campaigns or extension services. Where surgery is required to correct these problems acetylpromazine and xylazine are satisfactory sedatives and can be used safely with ketamine as a general anaesthetic.

Cases of equine degenerative arthritis have been reported in Central America. These are probably associated with deficiencies of minerals and vitamins in the diet. Other problems of an anatomical nature include cryptorchidism; in one area in northern Nigeria 30% of donkeys were cryptorchids and in 70% of these it was the left testicle that was affected. This condition is highly heritable and was probably prevalent here because of in-breeding in small village herds. Libido was not affected as testosterone was secreted normally but spermatogenesis was inhibited due to the high temperatures in the area in which the retained testis was located (Kumie-Diaka *et al*., 1981).

Management

Except in a few special cases little that would be termed 'management' in the modern sense is practised on horses and donkeys in the tropics. As most donkeys and horses are not kept for meat or milk production but as transport animals they do, in fact, require less in the way of management than if their functions were more complex. Some supplementary feeding may be provided and where veterinary services are availablethese are often in urban centres where equines are gathered for transport purposesthey may receive considerable medical care. Equines indeed usually figure as the largest group of animals treated at veterinary centres.

Ownership Patterns

The number of equines owned per person or per family obviously varies widely as do the numbers of families owning them. In India where donkeys are present it is said that each family has one to provide it with its various transport requirements. In southern Iran, however, the Basseri people own 612 donkeys per family. Turkana families in northern Kenya averaging 20 people own 25 donkeys at a ratio of 1 donkey to 1.6 sheep, 10.4 goats, 1.4 camels and 1.4 cattle (Coppock *et al*., 1982). In the early years of the twentieth century the colonial administration in Kano in northern Nigeria estimated that there was 1 donkey for every 16 people (Ogunremi, 1982). Logically the number of equines owned should bear some relationship to the use made of them. Sedentary agricultural peoples might have less need of them for transporting water and moving camp but could need them seasonally for moving harvested crops from field to farm and from farm to market and for carrying crop residues as feed for other livestock.

In southern Mali the Bambara agriculturalists own an average of 0.71 donkeys per household but also own 1.92 work oxen. It is obvious that these oxen, being available and trained, fulfil many of the functions that would elsewhere be reserved for donkeys. In northern Mali 83% of Tuareg families own 2.4 ± 1.3 donkeys whereas 54% of Fulani own 2.1 ± 0.9 donkeys. Requirements of these two last groups are probably about the same for transport of water and for moving camp. The difference in the actual number of donkeys per family, when taking into account the number of families owning them, can probably be explained by the fact that the Fulani use cattle as transport animals but the Tuareg do so to a much lesser extent. In areas where Tuareg clans own camels the donkey requirement would also be less.

In Shewa Province in highland central Ethiopia, 85% of households own or keep donkeys, 62% own or keep horses, and about 10% own mules (Fig. 13.8). Average numbers per household are 2.3 donkeys, 1.6 horses and 0.2 mules. For all species combined, 90% of households own at least one equine, the overall average being 4.2. In this area, 11% of all domestic herbivores are equines, equivalent to 28% of total biomass. The relatively large weight contribution is because many other animals here are sheep and of light weight (Wilson, 1991).

Farther north in Ethiopia, in central Tigray, 49% of households kept donkeys, 3% kept horses and 10% kept mules in the mid-1970s. Average donkey numbers per household were 0.6, those for horses and mules being 0.1. Equines were 10% of all animals and 11% of biomass. The low figure for biomass is because a large proportion of the animal population in this area was mature heavy draught oxen.

Population Structure

In many areas equines are used only for transport, males and females are used indiscriminately and there is no off-take for slaughter or sales for other reasons. Population structure then almost certainly represents the most natural of all domestic animals. In such a situation, typified by donkeys in an agropastoral system in western Sudan (Wilson, 1978a), the sex ratio does not differ from a 1:1 ratio and the age distribution depends on the birth rate and the

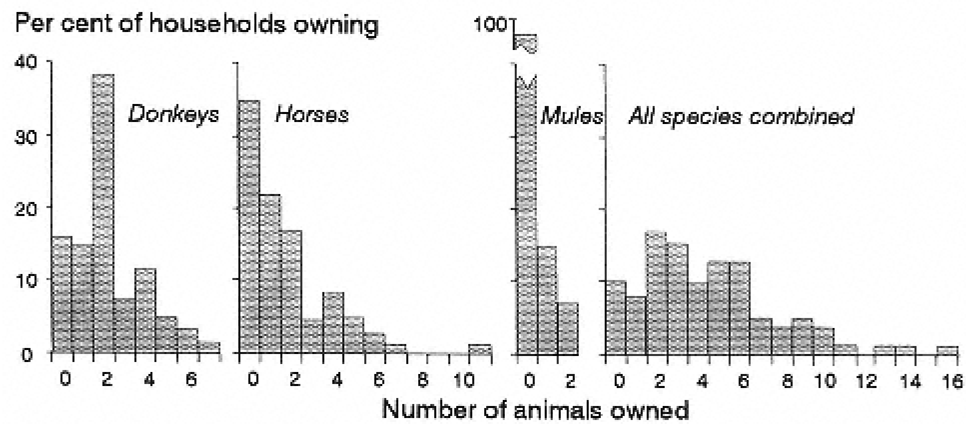

Fig. 13.8
Ownership of equines by 120 households in the Debre Berhan area of highland Ethiopia in 1984.
(Source: Wilson, 1991.)

Table 13.6 Age and sex structure of some African donkey populations. (*Source*: Wilson & Wagenaar, 1983.)

Age		Country and sex						
Teeth	Chronological	Niger (*n* = 365)			Sudan (*n* = 449)			Ethiopia (*n* = 277)
		Male	Female	All	Male	Female	All	All
Temporary incisors								
1 pair	<8 weeks	0.3	0.0	0.01.1		1.1	2.2	0.0
2 pairs	836 weeks	3.6	3.0	6.63.5		3.5	7.1	8.3
3 pairs	930 months	11.6	15.1	26.89.8		12.1	21.8	23.5
Permanent incisors								
1 pair	3042 months	2.5	6.0	8.54.5		2.9	7.4	13.7
2 pairs	4254 months	4.1	9.6	13.74.9		5.3	10.3	6.6
3 pairs	5472 months	6.6	26.8	33.427.6		23.6	51.2	22.0
3 pairs + canines	>6 years	1.1	9.0	10.1				25.6
Total		29.9	70.1	100.051.4		48.6	100.0	100.0

longevity of animals (Table 13.6). In general terms in these types of herds about one-third of all donkeys are young animals of less than 30 months of age regardless of whether the herd is mostly female or equally distributed between males and females (Table 13.6). These examples probably indicate similar reproductive and mortality rates and little interference with herd structure by the owners except where there is a market for bigger and stronger male animals for transport in urban areas.

On mixed smallholdings in central Shewa, in Ethiopia, 27% of donkeys are male and 73% are female. Some horses, equivalent to 5% of the population, are castrated while 26% are entire males and 69% are females. Mules showing external male genitalia are equivalent to 20% while phenotypic females are 80%. Based on dentition patterns, male donkeys under 42 months old comprise 71% of all males while females in this age category are 36% of all females. Some 46% of donkeys are females over 42 months and are

the potential breeding reservoir. Entire male horses under 42 months comprise 50% of all males. Female horses under 42 months are equivalent to 25% of all females and potentially breeding females in excess of 42 months are 54% of the total herd (Wilson, 1991).

Equines are still widely used in the tropics in landless urban systems. In Morocco, some 57% of the equine population are donkeys, 11% are horses and 32% are mules. The northern city of Fez is largely serviced internally by 2000 equines of which very few are horses (these are 'prestige' animals), 56% are donkeys and 41% are mules. Because the work of removing urban rubbish from the narrow streets of the old town and the transport of market goods into it is heavy and tiring 84% of the equine population are male and 96% are over 5 years old (Bakkoury & Belemlih, 1991). This important city represents a potential market for equines from the rural areas.

These contrasting systems allow a hypothesis of herd function of equine populations. Work is important in all types of herds but it less demanding of time and lighter in agricultural than in urban systems. In the Ethiopian agricultural area donkeys work an average of only 8.3 hours per week while in the Moroccan urban system work is demanded for 10 or even 15 hours per day. These needs have resulted in many areas in a stratification of donkey herd structures from breeding to work herds (Table 13.7). Low work demand and a need for cash allow sale of males from pastoral herds and retention of females to breed more animals. High work loads and the opportunity to earn cash create a demand for these males in urban areas.

Productivity

Productivity arises from reproduction ('breeding'), individual and herd growth, provision of meat or milk and, particularly in the case of equines, use as a source of power.

Individual Growth and Increase in Numbers.

In western Sudan the average growth of donkeys to 8 weeks of age was about 430 g/d, from 8 weeks to 9 months about 130 g/d and from 9 to 30 months about 110 g/d. At 30 months donkeys weighed about 75% of final adult weight and growth from this age to the asymptote was slow at 45 g/d to 3.5 years, 35 g/d to 4.5 years and then 20 g/d to mature weight at about 6 years.

There appears to be little firm information on herd or total population growth other than that provided by FAO statisticswhose data for this little-known group may not be very accuratewhich show very low total growth rates.

Meat Production

Almost nowhere in the tropics are equines reared for meat. One exception is the Turkana areas of northern Kenya. In many other areas, especially parts of continental Europe and Central Asia, meat production is an important function of horses. In Australia some efforts have

Table 13.7 Demographic structure (%) of donkeys in various types of production systems in Africa.
(*Source*: Wilson & Wagenaar, 1983.)

Country/system	Sex and function				Herd function
	Male		Female		
	Total	'Working'	Total	'Breeding'	
Niger/pastoral	29.9	20.2	70.1	51.5	Reproduction, sale, work
Sudan/agropastoral	51.4	41.8	48.6	31.9	Work, reproduction
Mali/agropastoral	69.4	56.4	30.6	19.3	Work, reproduction
Mali/urban	85.4	83.0	14.6	11.3	Work

been made to convert the feral donkey population into pet food but these have not proved economically viable. Australian aboriginals are said to eat donkey flesh on occasions.

Milk Production

Milk is rarely a direct economic product of equines. The major exception is in the nomadic areas of Central Asia where, slightly soured as 'kumiss', it is highly valued.

Dual Functions

In central Ethiopia, most animals are primarily dual-purpose, breeding being the main function and transport the secondary function (51% of donkeys, 54% of horses) or with transport the main function and breeding the secondary function (8% of both donkeys and of horses). A few animals are kept purely for breeding (2% of donkeys, mostly jacks for breeding mules, and 1% of horses) or purely for transport (6% of donkeys and 16% of horses including all the geldings). Remaining animals are 'growing' (i.e. animals intended as replacements) although 5% of donkeys and 1% of horses are both growing and used for transport. Most mules are 'growing' (53%) but 10% are growing and providing transport while 37% are used for transport only (Wilson, 1991).

Work

Equines provide work as saddle and pack animals, as pullers of carts, as draught animals for cultivation, as prime movers for lifting water from wells and for minor industrial purposes. In India, in addition to use for domestic transport, they are used by builders, potters, tinkers and washermen. In these last functions donkeys are expected to carry loads of 2268 kg at speeds of 3 km/hour and travel 24 km/day. Specialist racing donkeys bred in certain parts of India may cost more than 10 times the amount of a simple work animal.

General Transport

Most equines are used mainly in the immediate locality but some are used for long distance transport. In Africa in the late nineteenth century donkey trains of 200300 animals (and occasionally as many as 700) carried tobacco from Kano in northern Nigeria some 400 km to the north where this was exchanged for soda (natron). The soda was then transported to Ilorin and Ibadan in southwest Nigeria, perhaps a further 1000 km. The train then returned to its home base loaded with cola nuts (Ogunremi, 1982). The administration at that time was not very much in favour of donkeys but admitted that they were cheap (about 60% of the price of an ox but with a lot more stamina), easy to feed, had a small food requirement and needed little attention.

Most off-road transport in eastern Nepal is provided by human power. In central and western Nepal, however, the Equidae take their place alongside yaks, goats and sheep (all of which carry loads on their backs) as providers of transport. Ponies in the Himalayan areas are also used for direct agricultural operations in much the same manner as cattle at lower altitudes. Equids are occasionally ridden and there are a few horse-drawn taxis (locally known as 'tonka') in some Terai towns. Mules are relatively numerous in the western region of Nepal around Pokhara where trains of 2030 animals are not an uncommon sight. Some are bred in Nepal but many continue to be imported from India. Nepalese mules, as might be expected from their parentage, are small (100110 cm) and have poor conformation. In spite of this they are still expected to carry loads of 80100 kg over long distances and rough terrain. The most common burden is two cans of kerosine or diesel fuel (Wilson, 1997).

Human Transport

In Ethiopa's Shewa Province, mules are a prestige animal. They cost rather more than horses to buy and considerably more than donkeys. It is not true to say they have care 'lavished' on them but because of their prestige and cost they are marginally better treated and rather better fed than donkeys or horses. They are used here almost exclusively for riding and often carry two people at a steady trot for long distances (Fig. 13.9). Unlike horses, mules are never harnessed in carts or in the two-wheeled 'gharis' or taxis that are a prominent feature of Shewa towns and larger villages. Similarly, they are rarely used as pack animals, this function being delegated to the lowly donkey. As a result of being used as riding animals, mules spend more time inactive than the two other species, as their owners' pre-occupations are often in attending political meetings or socializing in the numerous bars.

Pack Animals for Salt

In Tigray in Ethiopia and in Eritrea mules are used as riding animals and in several other ways. Occasionally unconventional rolesin the local contextare forced on mules. In 1975, for example, Tigray was suffering from one of its recurrent droughts and many oxen, most often used in plough teams, had died. Mules were therefore pressed into service as makeshifts but were always put into a span with an experienced ox. The mule's principal role in Tigray, however, is to transport salt from the Danakil desert to the highlands (Wilson, 1976). In this capacity mules, in the mid-1970s, earned their owners more than 1000 Ethiopian dollars a year, an enormous sum compared to the national average income. In earning this money, mules travelled approximately 12 times a year to the desert covering a distance of 180 km in each direction on each trip. Salt was carried up from the desert at 150 m below sea level to an altitude of more than 3000 m above it. Average loads, of 13 blocks of salt, weighed about 77 kg (Table 13.8). The long uphill journey took 4 days, initially in the torrid 4550°C heat of the desert and then in the below freezing temperatures of the highland nights.

Agricultural Transport

Donkeys and horses are important in supplying the thinly spread towns of western Sudan with water and fuel wood. In this area, however, the major function of donkeys is on-farm transport and then further transport from farm to market. Ponies are used for carting in Vietnam.

Fig. 13.9
A riding mule in highland Ethiopia

A donkey cart loaded with firewood in semiarid Mali.

Table 13.8 Economic and physical contributions of pack animals to the northern Ethiopian salt trade in the early 1970sa. (*Source*: Wilson, 1976.)

Parameter	Species		
	Camel	Mule	Donkey
Total value of excise duty (Ethiopian $)	198 952	172 093	60 680
Contribution to excise duty (%)	46.0	40.0	14.0
Ratio of animals	1.00	1.73	1.22
Total journeys per year	66 317	114 729	80 907
Individual load (kg)	89.7	77.0	49.2
Salt transported (t)	5 949	8 834	3 981

a Financial data from Government records; physical data based on sample of 4200 animals.

Low-level aerial surveys in western Darfur, Sudan, gave an estimate of 280 000 ha of cropped land on which the yield was about 1.5 t/ha to give a total crop output of 420 000 t. Average distances from field to farm were 3 km and thus donkeys provided 1 260 000 tonne kilometres of transport. In addition it is estimated that 25% of the crop was moved once to market by donkey, an average of 10 km for a total of a further 1 050 000 tonne kilometres. At 1977 prices lorry transport was 10 piastres (US$0.28) per tonne km. The transport value from this function alone was thus £Sud231 000 (US$647 000) equivalent to a return of £Sud6.6 (US$18.50) per donkey per year. A typical Sudanese donkey cost £Sud5.00 in 1977 and had a productive life of 5 years. The annual return to a donkey in economic terms was then more than 600%, excluding the negligible cost to a farmer of the common feed resource and, of course, the imputed value of his own labour.

Cart Transport of Fuel Wood and Building Materials.

The donkey is primarily used as a pack animal in which role it can carry about half its own weight as a load. Between the shafts of a two-wheeled locally constructed cart it can easily pull seven to ten times this amount with loads of 500 kg per animal being perfectly feasible (Fig. 13.9). A survey of transport into the Malian town of Niono, a centre of 15 000 inhabitants, but expanding at an annual rate of at least 12%, provided an estimate of 185 240 movements of which 97.5% were by donkeys. More than 70 000 tonnes of various commodities (Table 13.9) arrived in Niono in a year, or 5 t per person living there. More than 75% of total transport volume was represented by locally gathered and produced building materials, an eloquent testimony of the rapidly expanding nature of an African urban area. A more disturbing interpretation is inferred from the amount of fuel wood, totalling 0.5 m3 solid volume per person per year. In this area, that represents the natural increase of 0.5 ha of bush land and has obvious implications for sustainability and environmental degradation.

For donkey owners, nevertheless, economic returns were very attractive. Building material transport provided an income of US$2340 per year at 1980 prices for a 6-day week. Should he prefer to cart fuel, income would have been US$1460. Returns to these endeavours, with a donkey price of US$110 and a cart price of US$280 and exclusive of labour, were thus 600% and 375%, respectively. In practice most owners operated a combination of two enterprises because of the heavy toilfor man and beastof building material work. Even so, returns were exceptionally high in relation to the Malian gross national product (GNP) of US$110 at that time.

Domestic and Livestock Water Supply

As draught animals, most species exert a pull of about 10% of their own weight, tractive effort

Table 13.9 Annual entries of animal transport into Niono, central Mali (population 15 000). (*Source*: Wilson, 1990.)

Item	Donkeys with carts						Pack and riding donkeys	Other animals
	Wood	Building earth	Sun- dried bricks	Vegetables and grain	Straw and fodder	Other		
Percentage of all entries (%)	8.3	36.7	17.4	9.3	3.5	11.8	10.7	2.5
Number of loads								
Mean per daya	42.0	186.1	88.4	47.0	17.6	59.7	54.3	12.5
Total annual	15 319	67 926	32 251	17 155	6 424	21 798	19 809	4 559
Load weight (kg)b	367	311	459	400	150	150	75	
Amount transported								
Total annual (t)	5 622	42 250	14 803	6 862	904	3 270	1 486	
Per inhabitant (t)	0.37	2.82	0.99	0.46	0.06	0.22	0.10	

a Other animals include 1.0 ox carts, 0.6 ridden oxen, 6.2 saddle horses, 4.4 ridden camels, 0.4 pack camels.
b Estimated loads for last four columns; other loads included corpses, brides, motor vehicles, farm tools and sick animals.

being the product of resistance to pull (the load weight, including friction and gravity effects) and the speed of movement. At a well of 51 m depth in Mali, donkeys lifted 15.9 litres of water plus the 6.6 kg of rope and bucket to the surface at an average speed of 0.94 m/s. Initial draught was 30 kg due to inertia but then settled to about 25 kg, and donkeys thus developed a power output of 23.5 kg m/s or about 20% of body weight. Oxen at the same well developed only 61.2 kg m/s or about 1214% of body weight. The nature of the work, involving short bursts of energy with relatively long rest periods probably accounts for the high power output by donkeys.

A round trip, between emptying one bucket and the next, took 1 min 20 s, theoretically equivalent to 45 trips an hour or about 700 litres of water lifted. Actual operating rates were only 13.3 trips but for reasons outside the donkey's control (social sparring by the owner, broken ropes, etc.) and donkeys only worked a 3.5 hour/day. The actual water lifted was thus almost 700 litres, sufficient for 35 cattle or 170 sheep and goats or 70 people. A typical 'six donkey' well thus provides a sustained output of 1200 litres/hour. This compares very favourably with small motor pumps and may, in fact, be greater than the recharge capacity of many wells in dry areas. The donkey system requires little capital outlay, no spare parts not obtained from within the system, is self-perpetuating and self-fuelling and, above all, is understood by and adapted to the needs of the people who use it.

Constraints to Increased Productivity and Opportunities for Development

Equines are once again assuming increasing importance as power sources in many spheres of production. Power to weight ratios are certainly better in horses than most other species and, where the load is of suitable size, are better in donkeys than in cattle. In Pakistan, donkeys have been shown to be able to pull more weight in relation to their body mass than any other domestic animal than the camel but in economic terms they were more efficient even than these redoubtable animals (Hanjra *et al*., 1980). When lifting water from wells a typical 'six donkey' model can move enough water per hour from 50 m below ground to provide sufficient for the requirements of 70 cattle or 340 goats and sheep or 140 people or any combination of these.

In spite of these telling examples, draught for arable operations is usually considered the principal, if not the only, use of domestic animals in providing power. In the face of the world energy crisis, research on draught is gaining momentum but research on other work applications is still somewhat neglected. Total support to human welfare by providing transport through pack operations, drawing carts, as riding animals or harnessed to taxis almost certainly contributes more to the agricultural economy than arable draught operations such as ploughing, ridging or harrowing. Animals also aid economic progress as prime movers for water lifting, earth moving, and for small industrial and forestry operations. Equines predominate in these often unconsidered roles and their full economic value as producers, when they are often thought of simply as consumers, is often grossly underestimated.

Some advantages of animals over machines in the context of the current world economic situation are: low initial cost; suitability for small units with limited output; sustainable and self-perpetuating if both males and females are used; concomitant lack of need for spare parts and thus low running costs; and finally no need for foreign exchange.

Reviews of the sparse available literature clearly show that there has been very little research on power applications other than for land preparation. In Ethiopia, for example, it appears that the 'ghari' (a light two-wheeled horse taxi) and some carts were introduced to towns and industrial crop areas during the Italian occupation (Vitali & Bartolozzi, 1939). Station experiments with 'improved' (i.e. Western) implements for horses and mules (Wiggins *et al*., n.d.) probably failed, not as the authors thought because the animals were too weak, but because the technology was ill-adapted to local needs and to farmers' levels of training and skills. Some 'development' has, however, taken place. Successful examples are the introduction of donkey carts and cart-mounted water tanks to areas where they are not traditionally used. Other developments, such as the use of primitive oil mills in the northern lowlands of Eritrea, have been more or less spontaneous and connected with the common heritage of the tribal groups on the Eritrean and Sudanese sides of the national frontiers.

Lack of knowledge of energy needs for work, and therefore the feeding of working animals, is a constraint to economic use. Some preliminary results indicate a cost of 3.31 J/kg transported per horizontal metre and 23.0 J/kg per vertical metre (Yousef *et al*., 1972). It thus seems that energy requirements for transport are not very high.

The scope for increasing productivity by the use of simple, appropriate and sustainable technology is enormous. Even where animals are currently used in work functions other than for cultivation, traditional methods are not very efficient. In addition to the obvious transfer from pack to cart (entailing a possible 10-fold increase in the load factor for donkeys) the use of capstans for seed decorticating, oil milling, lifting water and threshing and of sledges for transport and threshing, would also improve efficiency (Table 13.10). Improvements would be cost, energy and resource saving. Difficulties in implementation of research and development should not be used as pretexts for not at least attempting

Table 13.10 Time expenditure and costs of three animal-powered threshing methods.

Method	Men		Oxen		Batch (kg)	Cost (100 kg)
	No.	Hours	No.	Hours		
Trampling	3	9	6	18	200	0.68
Sled	3	7	4	10	300	0.37
Thresher	2	4	4	8	400	0.28

to use this important resource better than is now the case.

In sum, very little attention has been paid to the social and economic role of equines in the tropics. These hardy, hard-working and well-adapted animals have been taken for granted by owners, development and research workers and politicians (and indeed are often brushed aside by the last group as being 'primitive' and old-fashioned). Continuing economic difficulties, especially related to obtaining foreign exchange to pay for expensive fossil fuel, are leading to some attitude changes. The low cost, ecologically sound and sustainable contribution that equines can make to improving the quality of life of millions of the world's people deserves better recognition.

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Further Reading

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14
Pigs

Introduction

The primary purpose of pig farming all over the world is the production of meat, including pork, bacon or fat. Secondary considerations are the production of pigskin, bristles and manure.

In the tropics fresh pork has always been and continues to be the most important type of pig meat, but elsewhere processed meat is produced in large quantities, probably because pig flesh can be more effectively preserved with salt than can other types of meat. Processed pork is now finding a ready acceptance among many consumers in tropical countries and consumer preferences are slowly changing everywhere as industrialization advances.

Pigskin has generally been used only for the manufacture of light leather goods and its production has been localized, as has the production of pig bristles.

Pig manure is useful everywhere: as a fertilizer, either for the soil or for fish ponds; for the production of methane gas; and for the culture of algae such as chlorella and azolla that can be used as an animal feed. It contains on average 0.70, 0.68 and 0.70% of nitrogen, phosphorus and potassium, respectively.

An advantage of pig farming that is now becoming apparent in some tropical countries is that on account of the pig's high fecundity and growth rate, pig production can yield a relatively rapid rate of return on the capital employed.

The Worldwide Distribution of Pigs

The pig is omnivorous and in some respects competitive with man for food, but is also a very useful consumer of the by-products and wastes from human feeding. Thus pigs are usually most numerous where human food is cheap and plentiful and/or where there are large quantities of by-products or offals available. The size of the pig population of any given region also, of course, depends upon other factors, for example the climateonly a small number of pigs being found in the arid areas of the worldand the social and religious beliefs of the indigenous people, there being few pigs in countries with a predominantly Muslim population.

The distribution of the world pig population on a continental and tropical/non-tropical climate basis is shown in Table 14.1. It would appear that 17% of the world pig population is managed in the tropics. This is, however, an underestimate. Part of the southern China mainland and Hainan Island are located south of the Tropic of Cancer, but the number of pigs within this area is unknown, so they form part of the total Chinese pig population that is listed as nontropical. It is therefore possible that the total tropical pig population is closer to 20% than to 17% of the world population. It will be seen from Table 14.1 that for the period 196494, with the exception of China, the pig population grew more rapidly in the tropics than in the nontropical regions.

Table 14.1 The world's pig population. (*Sources*: FAO, 1965, 1995.)

Continent region	Pig population (1000) 1964	1994	1994 as % 1964	1994 population as % world total population
Africa				
Tropics	3 871	19 413	501	2.4
Other	1 658	1 671	101	0.2
Americas				
Tropics	13 042	61 190	469	7.5
Other	63 471	81 942	129	9.9
Asia				
Tropics	29 979	54 964	183	6.8
Other	24 827	25 079	101	52.2
China	200 761	402 846	201	
Europe				
Other	139 591	167 983	120	20.4
Oceania				
Tropics	1 302	2 289	176	0.3
Other	1 945	2 622	135	0.3
World	480 447	819 999	171	
Tropics	48 194	137 856	286	17.0
Other	432 253	682 143	158	83.0

Of all the pigs in tropical regions, 14.1, 44.1, 40.0 and 1.8% are managed in Africa, the Americas, Asia and Oceania, respectively. The percentage within Asia would be higher if the pigs in tropical regions of China were included in the total for the Asian tropics. Growth in the number of pigs during the 196494 period was most rapid in Africa, where total numbers are relatively low, and in the Americas.

The major regions of pig farming in the tropics are: the non-Muslim countries of Southeast Asia where fresh pork is the major product but manure production is also important; countries in Central and South America where until recently lard production was important but where meat production is now more important; and islands in the Caribbean, Indian Ocean and the Pacific Ocean where pork is one of the main sources of animal protein for the population.

In South Asia, except for limited areas, domesticated pigs are barely tolerated and the relatively few that are raised are badly managed and rather unproductive. The number of pigs in North and Northeast Africa is small but in the more humid non-Muslim regions of West Africa there are indigenous breeds increasingly used for crossbreeding with temperate-type breeds. In East and Central Africa relatively small numbers of temperate-type pigs are managed at comparatively high managerial standards.

Origin of Domestic Pigs

It appears that the ancestors of the common domestic pig belonged to a single wild species, *Sus scrofa*, formerly extant throughout Eurasia and also found in North Africa and the Nile valley. *Sus scrofa* is a member of the Suidae family, of the order Artiodactyla. About 25 subspecies of *Sus scrofa* have been described (Clutton-Brock, 1981) and it is assumed that these evolved as adaptations to localized environments. In addition, there are four other *Sus* species and one related animal (National Research Council, 1983), found only in Southeast Asia. These are:

• *Sus barbatus* (the bearded pig). A quite large (<150 kg) animal with a red or black coat found in the Philippines, the islands of Borneo and Sumatra in Indonesia and the Malay peninsula. It has not been domesticated, but it hybridizes with *S. scrofa*, both sexes being fertile.

• *Sus celebesis* (the Sulawesi warty pig). A medium-sized (<70 kg) animal, with a red/brown coat. It is found in Sulawesi and other eastern islands of Indonesia. It has been domesticated on the island of Roti and is one of the ancestors of domesticated New Guinea pigs.

• *Sus verrucosus* (the Javanese warty pig). A large (<120 kg) animal with yellow, red or black hair, found in Java and some adjacent islands of Indonesia. It has not been domesticated, but it hybridizes with *S. scrofa*. It is an endangered species.

• *Sus salvanius* (the pygmy hog). A very small (<10 kg) animal once widely distributed in the foothills of the Himalayas, now only known definitely to occur in the Manas National Park in Assam, India.

• *Babyrousa babyrussa* (the babirusa). A piglike animal living in the forests of Sulawesi and adjacent islands of Indonesia.

There are two conflicting theories as to the origin of domestic pigs. One is that they were independently domesticated at centres in several different regions. The other is that they were domesticated at one centrein Western Asiaand that domestic pigs were gradually diffused from this centre into the remainder of Asia, Europe and Africa. Epstein & Bichard (1984) have, for example, stated that the presence of the domestic pig at Cayonu in southeast Anatolia, Turkey (*c*. 9000 BP (before present)), antedates its appearance in all other centres by several centuries. Earlier, Epstein (1969) suggested that the pig was domesticated in China in Neolithic times, possibly *c*. 5000 BP, but more recently Cheng Peilieu (1984) stated that it was domesticated at least 67000 years and possibly 10 000 years ago. There is also evidence (Clutton-Brock, 1981) that there may have been domestic pigs in New Guinea, not necessarily of the species *Sus scrofa*, about 9000 years ago.

The conflicting archaeo-zoological and other evidence suggests that domestication of the pig probably occurred at more than one centre, but that with the exception of those on some Indonesian islands and in New Guinea, domestic pigs have been derived from one or other of the many subspecies of *S. scrofa*. Three subspecies may have been of particular importance: *Sus scrofa scrofa* the Eurasian wild pig, *Sus scrofa cristatus* the Indian jungle pig and *Sus scrofa vittatus* a wild pig of Southeast Asia.

Even if it is accepted that domestic pigs first spread into Europe and into North and Northeast Africa from a centre of domestication in Western Asia (Epstein & Bichard, 1984), their origin and their mode of spread in East and Southeast Asia is still unclear. The evidence suggests that pigs were independently domesticated in these regions, possibly at a number of different centres. Whether these domestications occurred at an earlier or at a later period than those in Western Asia, is not evident at the present time.

Asiatic types of the domestic pig were introduced into the Mediterranean region in Roman times to produce what came to be known as the Neapolitan pig. Domestic pigs from China and Southeast Asia were introduced into Europe by the Portuguese in the fifteenth century and into Central and South America by the Spanish and Portuguese in the sixteenth century. In the latter part of the eighteenth century Chinese, Southeast Asian, Portuguese and Neapolitan pigs were introduced into Britain for crossbreeding with the local domestic pigs. The ultimate result was the development of modern British and other West European breeds. In North America pigs from many sources were imported, including the newly developed breeds from Britain. At first, the majority of these pigs were bred to convert cereal grains into lard, but as the market for lard declined they have been bred primarily for lean meat production.

Today, everywhere in the tropics, indigenous breeds are being upgraded or replaced by imported, exotic breeds, particularly of British,

American and Scandinavian origin, as it has been found that these breeds will generally thrive in the tropics if they are properly fed and managed, and they are invariably more productive than the indigenous pigs. Thus some pigs with more or less the same ancestry are now to be found everywhere in the tropical world.

Wild pigs still exist and are indigenous in parts of Eurasia, North and Northeast Africa and some offshore Asian and Pacific islands such as New Guinea. In North, Central and South America, the Caribbean, Australasia and the majority of Pacific and Indian Ocean islands, any wild pigs that exist are feral and have been introduced by man.

Breeds Used in the Tropics.

Pig breeds useful in tropical environments may be classified in several ways. First, according to their utility and the major products that they produce, i.e. pork meat, bacon, lard, pig skin, bristles or manure. Secondly with regard to their skin colour that can be black, some other colour or white, as this characteristic determines in some respects how they should be managed. Finally, whether they are developed breeds of worldwide importance that are used in the tropics, developed breeds whose worldwide importance has waned but may still be useful in the tropics, developed breeds of local importance and undeveloped indigenous breeds that could become extinct.

Porter (1993) has published a comprehensive and useful guide to the pig breeds of the world while King (1991) has attempted to assess the relative importance of the breeds and their adaptability.

In previous editions of this book pig breeds were discussed in the context of their geographical origin and degree of development. In this edition, however, using some parts of the classification suggested by King (1991) we consider the breeds that are of worldwide importance in the tropics, those of limited and/or of regional importance and the indigenous breeds that are likely to become extinct unless present policies change.

Breeds of International Importance

King (1991) listed four breeds of international importance: Large White, Landrace, Duroc Jersey and Hampshire.

Large White or Yorkshire

The influence of this breed, developed in the UK, has probably been more widespread than that of any other, but within the breed there is a great deal of variation in type. This may account in part for its adaptability under varying conditions. It is a large, long, white pig with a body neither as wide nor as deep as the lard-type pigs (Fig. 14.1). It is probably the most prolific of all British breeds and the sows are heavy milkers and good mothers. Although pigs of this breed are not very quick in maturing they are efficient converters of feed, being used primarily for the production of bacon in the temperate zone and pork in the tropics. They are also widely used in crossbreeding programmes. Unfortunately, Large White pigs are very susceptible to sunburn, especially at the base of their ears.

Landrace

There are many types of Landracethe most important being Danish, Swedish and German.

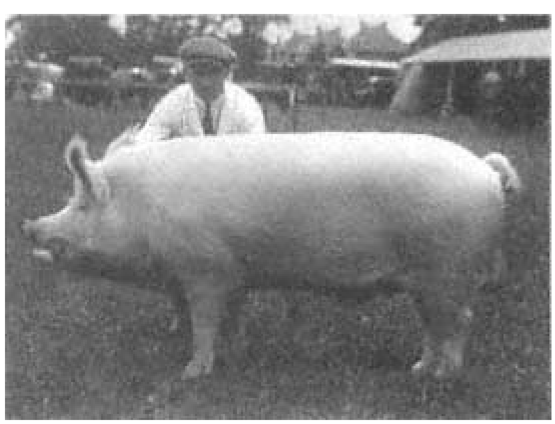

Fig. 14.1
Large White boar.
(Courtesy of G.S. McCann.)

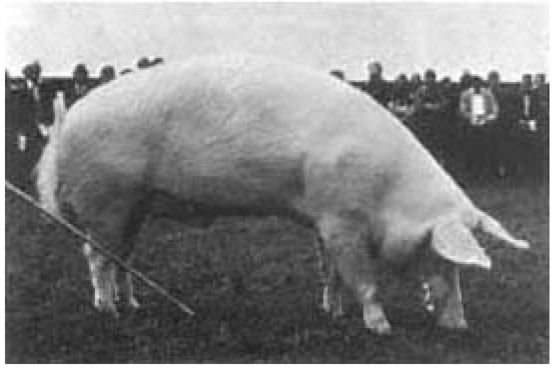

Fig. 14.2
Danish Landrace boar.
(Courtesy of Sales and Export Organization for
Breeding Pigs, Axelborg, Copenhagen.)

The Large White breed has played a prominent role in the development of all. The first Landrace breed to achieve prominence was the Danish (Fig. 14.2). It has probably been derived from the use of imported Middle White, Berkshire and above all Large White boars on indigenous female pigs, though this is disputed by Jonsson (1965) quoted by Epstein & Bichard (1984) who claimed that the original Landrace from Jutland, said to be the main foundation breed, was not crossbred to any extent. Selective breeding and progeny testing were later used to produce the long, all-white, bacon-type pig, characteristic of the Danish Landrace breed.

In Germany local Landraces were crossed with Large Whites to produce the German Landrace and the German Yorkshire. These two breeds, together with the Danish Landrace and the Large White have had a major influence on the development of breeds in Northern and Central Europe.

It is, however, the Swedish Landrace breed or its derivatives that has been widely used for crossbreeding purposes in the tropics, particularly in Southeast Asia. This is because Denmark stopped exporting breeding pigs. All Landrace pigs thrive under close confinement feeding, but they must be well managed. Certain strains exhibit a foot weakness and all are very susceptible to sunburn.

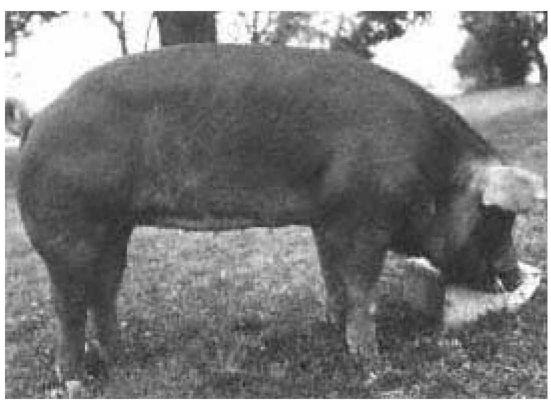

Fig. 14.3
Duroc.
(Courtesy of United Duroc Swine Registry, Peoria, IL.)

Duroc Jersey

These are large, red-skinned pigs of the lard type, noted for their feed capacity and fecundity. They originated in the eastern region of the United States and there is some controversy as to their ancestry. They probably developed from a mixture of Old English pigs, red guinea pigs from West Africa and red Mediterranean-type pigs from the

Iberian peninsula. During recent times the Duroc (Fig. 14.3) has been transformed by selective breeding from a lard- to a pork-type breed, and because of its colour and hardiness is popular both in Southeast Asia and in the American tropics.

Hampshire

These pigs are very distinctive in appearance as they are coloured black with a white belt around the forequarter of the body. They are medium in size, prolific, good nursing mothers and efficient converters of feed. They are the leanest breed of pig in the United States but their growth rate is only average. Consequently Hampshires are mainly used for crossbreeding particularly in the American tropics.

Breeds of Limited and/or Regional Importance

There are a number of developed breeds in Britain, Europe and North America that have been imported into the tropics, but have made no particular impact. These include the Craon, Edelschwein, Gloucester Old Spot and Piétrain. Other developed breeds have been used frequently in the tropics, either as purebreds or for crossbreeding purposes. These include the Berkshire, Large Black, Middle White, Tamworth and Poland China.

Berkshire

This is the British breed that was first brought to a high standard of perfection. In 1790 Berkshires were described as very large, black in colour, long and crooked snouted, with a long, thick but not deep body and short legs. Around 1800 the original type was crossed with Chinese pigs and later with Siamese and Neapolitan pigs. Today there are two distinct typesthe British pork type that is characterized by early maturity and medium fecundity, and the Canadian type that is slower maturing and is used for bacon production. The modern Berkshire is a medium-sized animal, black in colour with six white points on the feet, nose and tail, respectively. The ears are erect, the nose short and the face somewhat dished. The Berkshire is well liked and widely used in tropical countries.

Large Black

A breed developed by crossbreeding indigenous pigs from the eastern counties of England and Neapolitan pigs. It is a long, black pig with lop ears and good hams and is considered a good grazer and mother. It can be utilized for the production of pork or bacon and has been used extensively for crossing with indigenous pigs in various regions of the tropics.

Middle White.

This breed has been developed from the same basic stock as the Large White, but it demonstrates more influence of the Chinese pig than any other British breed. It has been extensively used in Southeast Asia to upgrade Chinese-type pigs, but it is no longer popular in Britain on account of the relatively fat carcase that it produces.

Tamworth

This is a breed developed in the West Midlands of England. Davidson (1948) stated that the foundation boar used for fixing the golden or chestnut colour was a jungle pig imported from India by Sir Francis Lawley of Middleton Hall, Tamworth, *c*. 1800. The Tamworth is a long, narrow pig with coarse hair, is usually considered slow maturing and is used for the production of bacon. In many respects it is the most undeveloped of all the British breeds. It is thrifty, very hardy and less susceptible to sunburn than many other temperate-type breeds. It has been widely used in crossbreeding programmes and it can be a very useful breed in those tropical countries where feeding and management are not of the highest standard. It is no longer used much in Britain and the breed is in danger of extinction.

Poland China

This is a very large, lard-type pig, well fitted to convert maize into fat meat. It is somewhat similar in colouring to the Berkshire. It has been used to some extent for crossbreeding in the American tropics as it is an efficient feed converter, but is no longer of importance.

There are two other types of imported pig that have contributed genes to the present pig population of the tropics. These are breeds from China and those from West European Mediterranean countries, particularly Portugal and Spain.

Chinese Pigs

It will be seen from Table 14.1 that about half the world's pigs are raised in China. There are many Chinese breeds, bred for differing human requirements in several different climatic environments (Epstein, 1969; Cheng Peilieu, 1984;

Porter, 1993). Breeds from the tropical and subtropical regions of China such as the Cantonese have been introduced into most Southeast Asian countries, probably by Chinese immigrants. Some were also introduced into Portugal and Spain in the fifteenth and sixteenth centuries. Subsequently, Chinese-type pigs or Chinese crossbreds were exported to islands in the Caribbean, Central and South America and West Africa. South Chinese pigs were also introduced into Britain in the eighteenth century and into the United States in the nineteenth century. In Britain they played an important role in the development of many British breeds whilst in America they were used in the formation of the Poland China and Chester White breeds.

The Cantonese

The Cantonese, synonym Pearl River Delta, is the characteristic black and white sway-back type of pig indigenous to south China (Fig. 14.4). It is usually called the *Chinese* in Britain and the *Macao* in Portugal and Brazil. The head is small with a moderately dished profile; the back is hollow and the belly pendulous. It is very fecund. The average litter size is 12 and litters of up to 20 are not uncommon (Epstein, 1969). The number of teats possessed by the sows range from 14 to 16. Fat pigs weigh approximately 75 kg at 12

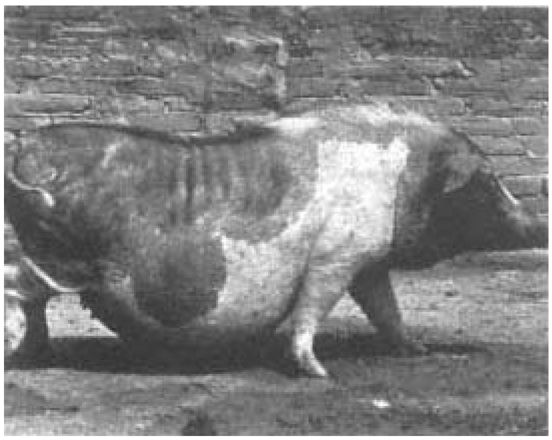

Fig. 14.4
South Chinese-type sow.
(Source: Epstein, 1969.)

months of age. Sows farrow twice a year and gilts are bred at 5 months of age (Phillips *et al*., 1945). The sows are said to be excellent mothers and piglet mortality due to 'overlaying' is low as the sow always lies down very carefully. Pigs of this breed are said to exhibit some tolerance of kidney worm and liver fluke.

Other breeds found in the tropical and subtropical areas of southern China are the *Wenchang* (Hainan), a small breed from Hainan Island, lop-eared pigs known as the *Northern Kwangtung* that are also very fecund, the *Luchuan* of Kwangsi and the *Ningsiang* and *Dawetze* of Hunan (Epstein, 1969). The *Taoyuan* breed of Taiwan is similar to the Cantonese.

At the present time the world's pig breeders are very interested in the early maturing and highly prolific Chinese breeds extant in Taihu, a non-tropical region in the lower Changjiang River basin. There are at least three types: the *Meishan, Fengjing* and *Jiaxing Black* (Cheng Peilieu, 1984). These are pot-bellied pigs adapted to roughage feeding, hardy and longlived, with lop-ears, a wrinkled skin and black or black/grey hair. Gilts come into first oestrus at 3 months when they weigh 1525 kg, while boars can mount and fertilize females at 3 months of age. Sows possess 1618 teats and by the third litter an average of 15 piglets are born while on average 12.5 are weaned. Growth rate and efficiency of food conversion are low, the backfat is 2050 mm thick and the carcase only yields 40% lean meat. The quality of the meat, however, is excellent.

The French, the British and the Americans (McLaren, 1990) have imported pigs of the Taihu-type in an attempt to incorporate their characteristic of high prolificacy in breeds of international importance. As the heritability of litter size is low at 0.10 in the breeds of international importance, it will be some years before it is known whether these attempts have been successful.

Portuguese and Spanish Pigs

Pigs of the Portuguese and Spanish Iberian-type breeds such as the *Alentejana*, *Black Iberian* and

Extremadura Red and/or Celtic-type breeds such as the *Bisaro*, together with crosses with imported Chinese pigs, were introduced into Caribbean islands, Central and South America from the fifteenth century onwards. Some Chinesetype pigs may have also been introduced to Mexico from the Philippines by the Spanish. Coloured Iberian-type pigs were also introduced by the Portuguese to West Africa.

Indigenous Tropical Breeds

Indigenous breeds of pigs are extant mainly in West Africa, South Asia, Southeast Asia and Central and South America. Although there are wild species of the Suidae family in Africa, there is no evidence that any have been domesticated. Present 'indigenous' breeds in West Africa are descended from imported pigs. The domestic pig was originally introduced into North and Northeast Africa but since the Arab invasions only remnant populations remain in North Africa. Egypt and in isolated areas in the southern Sudan. In East, Central and South Africa developed breeds have been introduced from Europe, however, in South Africa there is a breed known as the *Bantu*, believed to be derived from introduced European and Asian pigs. There are no indigenous domestic pigs in the tropical areas of western Asia.

West Africa

Domestic pigs are found throughout the forest areas of West Africa. Well-known breeds are the *Bakosi* in Cameroun, the *Ashanti Dwarf* in Ghana and the *Nigerian Native*. They vary in colour from black to white, are not very fecund, grow slowly, but are very hardy. The Ashanti Dwarf and possibly others are said to be trypanotolerant (Jollans, 1959). They were considered by Epstein (1971) to be of Iberian ancestry, but it is likely that they are pigs of more ancient ancestry that have been crossbred with Iberian-type pigs introduced by the Portuguese. In Côte d'Ivoire there is a breed known as *Korhogo* that has apparently evolved from crosses between Berkshire, Large White and West African pigs.

South Asia

Indigenous pigs in India are tolerated not managed. The *Ankamali* is a southern type, black in colour with white patches. The *Deshi*, with a rusty grey, brown or black coat, is found in the north while the *Ghari* (syn. *Nepalese*) a black dwarf type is found in Nepal. All are hardy, scavenger pigs. There is a similar type of pig in Sri Lanka known as the *Sri Lanka Native*.

Southeast Asia.

Many of the indigenous pigs in the region are of Chinese-type ancestry but there are exceptions. There has also been extensive upgrading using developed, mainly British breeds.

Burma

The *Burmese* is black in colour, while the *Chin Dwarf* is a very small breed, pigs weighing 30 kg at maturity.

Thailand

Virtually all breeds are of the Chinese type. They include a black pig known as the *Raad* or *Puang*, the *Kwai* a small black and white pig and the *Hailum* a black and white pig introduced from Hainan Island, China. All have been extensively upgraded using the developed European or American breeds.

Malaysia

There are domestic pigs with straight backs derived from the wild *Sus scrofa vittatus* and those derived from imported Chinese pigs such as the Cantonese. There has, however, been continuous upgrading with European breeds; first Middle White and Large Black and more recently Large White and Landrace. According to Marsh & Kanagaratnam (1938) the indigenous and Chinese breeds of pigs were more tolerant of

internal parasites than the imported European breeds.

Vietnam, Cambodia, Laos

Apart from breeds such as the *Meo* and the *Huang Kong* raised in the mountains, the numerous local breeds are of the South China type.

Indonesia

The *Javanese* is a crossbred of the indigenous and European-type pigs. The *Bali* is a black, lard-type pig of sway-back conformation. It is a hardy and prolific scavenger pig that has been exported to other islands in the Indonesian archipelago.

Sarawak

The *Iban* (syn. *Kayan*) breed (Fig. 14.5) is said to be a domesticate of the wild pig, *Sus scrofa vittatus*. These pigs are rather small, black or black and white in colour, with a narrow head, a long snout, a short neck and small, erect ears. They are used as scavengers, partly of human faeces.

Philippines

The *Ilocos, Jalajala* and *Koronadal* are swayback breeds that are usually black in colour.

Fig. 14.5
Typical Iban longhouse sow in Sarawak, Malaysia.

They are small and less prolific than the Cantonese and are almost extinct, being continuously upgraded by pigs of introduced American and European breeds.

Central and South America

Pigs in these regions have been used primarily as scavengers and to produce lard. A major breed in Mexico was the *Cerdo coscate* (syn. *Mexico Wattled*), a small (<60 kg at maturity) Iberian pig with a black or red coat, characterized by head wattles. A larger pig (>90 kg at maturity) with a black coat is the *Pelón de Cartago* from Costa Rica. A dwarf pig (<12 kg at maturity) with a curly coat and said to be of Chinese ancestry is known as the *Cuino*. This breed has been crossed with the Berkshire to produce the *Cuino de Pachuca*. Two other breeds of some interest in Central America are the *Creole* (Belize) and the *Honduras Swivel Tail* (Honduras).

In the *llanos* of Colombia and Venezuela there are Celtic-type pigs such as the grey, hairless *Zungo costeño* and semi-feral types such as the *Venezuelan Black*. These pigs are also known as *Criollo*. Brazil has a number of local breeds. One of the more important is the *Pirapitinga*, a nearly hairless, black or violet coloured, short-eared, lard-type pig of Chinese origin (Joviana *et al*., 1944). Similar breeds are the *Tatú* (syn. *Bahia*) and the *Macao*. The *Piau* is a smaller Iberiantype with a spotted black and white coat, while the *Pelón* and *Nilo* are black, hairless Iberian-type breeds. The *Canastrão* is a red- or black-coated Celtic type descended from the Portuguese *Bisaro*. It has been crossed with the Duroc to produce the *Pereira*, a lard-type pig. All these indigenous breeds have been crossed with American and British breeds and the identity of many of them is threatened.

Selection of Breeding Pigs.

Gilts from improved breeds can be selected for the breeding herd at 45 months of age, when they should weigh 6891 kg. Where it is possible they should be selected on the basis of records to ensure that they do not possess any inherited defects and that they come from families noted for large litters and early sexual maturity. The problems of genetic disease in pigs are discussed by Done & Wijeratne (1972). They should be healthy, possess sound feet, be well grown, have at least 14 prominent teats, a good carcase conformation and they should have exhibited a rapid rate of liveweight gain and good feed conversion efficiency up to the time of selection.

As on average only one or two boars have to be selected for every 50 gilts even more care should be taken in the selection of the boar. Individual record, pedigree, family information and, if available, performance and/or progenytesting information should all be used in the selection.

Artificial Insemination (AI)

In most tropical countries where the pig is an important domestic animal the majority of producers manage only a small number of sows. It is obviously costly and wasteful of resources for each producer to keep a boar, as one boar can service 50 gilts or sows per year. Even if a number of producers use one boar cooperatively there is a very real danger that he will transmit disease from one farm to another. Under these circumstances an artificial insemination (AI) programme has considerable relevance.

Unfortunately, there are at present real problems that prevent the widespread use of AI in pigs. Boars ejaculate approximately 200 ml of semen at one time, but this semen generally declines considerably in its capacity for fertilization after 1 day of storage and on average one boar's ejaculate can be diluted to inseminate only eight to ten females. Nevertheless, considerable progress is constantly being made in the techniques of storage and dilution of boar semen, and sows on heat will readily stand for insemination.

If the organization of an AI service for small farmers is contemplated in a tropical country, then expert advice should be sought as to the techniques to be employed and on the training of technicians.

Crossbreeding

Crossbreeding is the breeding method of choice for commercial operations in the tropics, as it is in the mid-latitude regions. The expected advantages that accrue from operating a crossbreeding programme are listed in Table 14.2. These advantages are due to crossbreds exhibiting hybrid vigour. Traits in which the most hybrid vigour is expressed being those with the lowest heritabilities; heritability being defined as that part of the total variability in characteristics between animals that is due to inherited traits.

Table 14.2 Expected advantages of crossbred over purebred pigs. (*Source*: North Carolina State University, 1967.)

	Expected advantage of crossbreds as percentage of purebreds	
	First cross	Multiple cross
	Boar: Purebred Sow: Purebred	Boar: Purebred Sow: Crossbred
Litter size at farrowing	0	5
Survival	7	12
Litter size at weaning	10	20
Liveweight at 154 days	11	14
Total litter weight at 154 days	22	30

Production trait	*Heritability*	*Hybrid vigour*
Litter size at weaning	*	***
Litter weight	*	***
Survival ability	*	***
Rate of gain	**	**
Efficiency of food conversion	**	*
Percentage lean in carcase	***	
Backfat thickness	***	
Body length	****	

Note: The relative degree of heritability or hybrid vigour is expressed by the number of asterisks.

Fig. 14.6
The relationship between heritability and the expression of hybrid vigour in some production traits of pigs.

The generally reciprocal relationship between hybrid vigour and heritability is shown in Fig. 14.6.

There are several methods by which continuous crossbreeding might be organized. One is to practise criss-crossing or a two-breed rotation. In this system boars of two different breeds are used in alternate generations. Another is triple crossing or a three-breed rotation. This latter system involves the use of boars from three different breeds and is based on the idea of capitalizing on particularly strong traits possessed by individuals of each of the three breeds selected.

It would be very difficult, if not impossible, for small-scale pig producers to operate continuous crossbreeding programmes. One solution to the problem of organizing a pig industry so that the small producers can use crossbred pigs would be for the government, co-operatives or private breeders to organize the distribution of crossbred gilts to small pig farms from a central crossbreeding station. Action along these lines is now being taken in several tropical countries.

As stated earlier, exotic breeds are now used all over the tropics and the indigenous breeds have been upgraded to such an extent that in many areas they have all but disappeared. This is an undesirable situation and an effort should be made in all countries to keep at least a limited number of purebred indigenous pigs. There are several reasons for this suggestion. First, some indigenous breeds may exhibit desirable traits needed in boars that will be required for use in continuous crossbreeding systems. An example of such a trait would be the very high prolificacy of some Chinese pig breeds. Secondly, indigenous pigs may exhibit traits that are not required or perhaps not even recognized as useful at the present time. Examples could be immunity to specific parasites and diseases and the ability to thrive on low-nutrient-content feeds. It would be a biological tragedy if these traits were lost for ever. Finally, there is an aesthetic and cultural argument for preserving at least a minimum number of pigs of all indigenous breeds that apparently have no economic value under present circumstances.

Reproductive Behaviour

Pigs are polyoestrus, females coming into heat on average at 21-day intervals (1924 days) throughout the year. Gilts tend to have a shorter heat period than sows. Within this cycle the heat period lasts up to 48 hours. Females in heat are characterized by grunting, restlessness and by a swelling of the vulva. The period of maximum fertility in the female occurs during mid-oestrus, some hours before ovulation. As the shedding of the large number of ova produced by the sow takes place over a period of several hours maximum fertilization can only be obtained with a reasonable degree of certainty by mating twice during the oestrous period. Service should therefore take place during the first day on which heat is observed and be repeated 1224 hours later. Service lasts much longer in pigs than with any other farm animals except the llamoids; as long as from 5 to 20 minutes. Some authorities advocate the use of a different boar for the second service as it is claimed that this practice tends to increase average litter size by approximately 1.01.5 pigs per litter.

Gilts should be bred for the first time on or after their third heat period. This should occur when they are 68 months of age and when they weigh approximately 100115 kg. It should be noted, however, that in some Chinese breeds and indigenous, tropical breeds the third heat period will occur at an earlier age and at a lower liveweight than in many temperate-type breeds. Sows may be bred at the first heat period after weaning if early weaning is practised and they are in good condition. Otherwise they should be bred at the second heat period after weaning.

Boars may be used for the first time when they are 78 months old as long as they are well grown. They are considered to be sexually mature at 15 months of age. A mature boar should be able to serve 2040 times per month if he is managed together with the females. Immature boars, under 15 months of age, should be used for service no more than 25 times per month. Boars must be kept in a thin, thrifty condition if they are to remain sexually active. A breeding crate should be utilized when old, heavy boars are used to breed gilts. Unless matings are seasonally concentrated, the ratio of boars to females can be 1:50. The average gestation length of pigs is 114 days (112120 days) so that it is possible for a sow to produce two or more litters a year.

Infertility

The economic importance of efficient reproductive behaviour is obvious. Infertility may be due to a multiplicity of factors including genetic abnormalities in the breeding stock, poor nutrition, disease and the effect of the climatic environment. There are a number of genetic abnormalities that cause infertility and strict culling should be practised to remove gilts or sows that do not conceive after the second breeding to fertile boars. Boars with genetic defects that affect fertility should never be selected for breeding purposes. As the nutrition of pigs is usually entirely controlled by the commercial farmer, the occurrence of infertility due to nutritional causes can only be due to poor feeding and/or managerial techniques and with good management should be minimal. The major diseases that affect fertility in pigs are brucellosis and leptospirosis, but fortunately these are not common in the tropics. Nevertheless, vigilance is required to prevent reproductive inefficiency due to disease.

Effect of Climate

Male sexual libido appears to be affected by the climate. Steinbach (1972a) stated that refusal to mount and ejaculate was positively related to the effective mean monthly temperature in Nigeria and that boars need more time to ejaculate during the hottest months of the year. In Large White pigs exposed to tropical sunlight for short periods, Egbunike & Dede (1980) have shown that although libido is unaffected, ejaculation time increases, sperm concentration and motility decreases and sperm abnormalities increase. Climate does not appear to affect the ovulation rate of female pigs. However, it does appear to affect the oestrous cycle. According to Steinbach (1972b), with pigs in Nigeria oestrus lasts longer during the cooler months and the incidence of missed heats increases when the ambient temperature rises above 23°C. This situation is confirmed by Serres (1992) who has provided data (Table 14.3) that shows that an increase in the ambient temperature from 2627°C to 33°C increases the number of sows failing to show heat and the number returning to heat after mating. Extreme heat may increase embryonic mortality (Edwards *et al*., 1968) and this is confirmed by an experiment conducted by Omtvedt *et al*. (1971). These workers investigated the effect of heat stress at 37.8°C for 17 hours and at 32.2°C for the

Table 14.3 The effect of ambient temperature on reproductive performance of pigs. (*Source*: Serres. 1992.)

	Ambient temperature (°C)		
	2627°	30°	33°
No. sows	74	80	80
No. sows on heat	74	78	73
No. anoestrus	0	2	7
No. returning	2	8	8
% pregnant sows	90.5	84.8	77.5

remaining 7 hours of the day, as against a controlled temperature of 23.3°C on first-litter gilts. They found that heat stress during the first 8 days after oestrus reduced the pregnancy rate at 30 days after oestrus by 43%, while heat stress from the eighth to the sixteenth day reduced it by 21%. The number of viable embryos was significantly lower in the stressed group in both periods. Heat stress during mid-pregnancy (5361 days) did not appear to affect the gilts significantly in any way. On the other hand, heat stress towards the end of pregnancy (102110 days) had a very significant effect on the gilts. In the stressed group two gilts died. The number of piglets born alive and stillborn were 6.0 ± 0.76 and 5.2 ± 0.62 in the stressed group and 10.4 ± 0.76 and 0.4 ± 0.62 in the control group, respectively. Of the piglets born alive 71.7% survived to 21 days in the stressed group and 88.5% in the control group. The results of this experiment and other evidence (Tomkins *et al*., 1967) suggest that in the practical management of breeding pigs it is particularly important to protect sows and gilts from extreme heat stress at the time of service and for some time afterwards, and again towards the end of the gestation period.

There is some experimental evidence that the gestation period may be slightly shortened in hotter climates.

Some reproductive and other data for a sow herd at Ibadan in Nigeria are shown in Table 14.4. Fecundity is about the same as it would be in the temperate zone, but weaning weights are low and the stillbirth and piglet mortality rates are high. It is not possible to state with any certainty what part of this lower productivity is due to the effects of the climatic environment.

Table 14.4 Data from the sow herd at Ibadan in Nigeria for the years 196769. (*Source*: Steinbach, 1973.)

Trait	Breed	
	Large White[a]	Landrace[a]
Conception rate (%)	67	61
Farrowing interval (days)	176	177
No. litters per sow per year	2.1	2.1
Litter size		
No. at birth	8.9	9.2
No. at weaning	7.0	7.2
Stillborn (%)	4.5	7.5
Piglet mortality (%), birth to weaning	21.4	22.2
No. pigs reared per sow per year	14	15
Litter weight (kg)		
At birth	11	13
At weaning[b]	42	44
Total weaning[b] weight per sow per year (kg)	86	91

[a] Descendants of Large White and Landrace foundation stock imported from the United Kingdom and Sweden, respectively.
[b] Age at weaning, 35 days.

Feeds and Feeding

The importance of proper feeding is very great as the cost of its food represents a very high proportion of the total cost of production of a pigsometimes more than 80%. This is because the pig grows so rapidly and consequently its food demands are very high. A baby pig may weigh 1.4 kg when it is born and 163 kg 18 months later. Thus in 18 months it multiplies its weight by 120, or it grows twelve times as fast as a calf that weighs 41 kg at birth and will weigh 408 kg 18 months later. If fed over-generous rations pigs fatten very rapidly. This tendency is highly heritable. It is also uneconomic.

The pig is omnivorous, i.e. it can eat all types of food, but although it likes to graze or chew forage in its pen it cannot digest too much fibre and unlike domestic ruminants it cannot live entirely on roughage. The pig has a very differently fashioned mouth and teeth from ruminants, being equipped to eat food on the surface of the soil or to root it out from the ground. Unfortunately pigs thrive best on those foods that are suitable for humans, but fortunately they also thrive on by-product feeds and other materials which are practically useless as food for man. If, however, the latter are the only feeds used the plane of nutrition often falls below the optimum level and the rate of liveweight growth is slowed down to an uneconomic extent. Therefore, it should be the pig farmer's aim to use the cheaper, lower-grade feeding stuffs to the fullest extent and to supplement them by the more expensive nutritious feeds to the point that true economy dictates.

Nutrient Requirements

Details of the nutritive requirements for pigs managed in the temperate zone may be obtained from publications by the UK Agricultural Research Council (1981) and the US National Academy of Science (National Research Council, 1973). A summary of some recommended nutrient allowances (McDonald *et al*., 1988) is provided in Table 14.5.

In the temperate zone practical rations for pigs are usually based on a daily feed allowance, as pig farmers aim to achieve the fastest possible growth without excessive deposition of fat. The protein in the feed must be adequate, not only in total amount, but also in the amount of individual essential amino acids as pigs cannot synthesise a number of thesethe most important being lysine and tryptophan. As the majority of pigs are pen fed, special attention must also be paid to the mineral and vitamin content of the daily feed.

The effect of high environmental temperatures on the nutrient requirements of the pig has not been fully explored. At ambient temperatures above the thermal neutral zone for medium-sized pigs (2025°C) there is a progressive decrease in total feed intake. This decreases total essential amino acid, mineral and vitamin intakes and it has been suggested that the crude protein, mineral and vitamin contents per unit of feed should be increased to compensate. Additional fat in the diet may be desirable as may be the amino acid supplementation of low quality protein diets (Serres, 1992). The evidence with regard to requirements for some vitamins is controversial. For example, it has been suggested by some researchers and refuted by others that riboflavin requirements decrease as ambient temperatures increase above the thermal neutral zone. Additional water will certainly be required by pigs as ambient temperatures rise.

Feeds Utilized

There are many suitable pig feeds available in the tropics. Details of some of the more important are provided in two FAO publications (Gohl, 1975; Pérez, 1997). Readers should also consult local publications for additional information. Some feeds that are widely used are listed below.

Feeds Containing Mainly Carbohydrates.

Cereals and Cereal Products

Barley

Barley is commonly used in Australia and in parts of Africa and Asia. It has

Table 14.5 Recommended nutrient allowances for pigsa. (*Source*: After McDonald *et al*., 1988.)

Component		Breeding Sows			Growing pigs liveweight (kg)b		
		Pregnancy	Lactation		Porkers	Baconers	Heavy pigs
			3 weeks weaning	58 weeks weaning	(2065 kg)	(5090 kg)	(65120 kg)
Feed	(kg/day)	2.0	5.2	5.2	1.2	2.2	2.4
Digestible energy	(MJ/kg)	13.0	13.0	13.0	14.0	13.5	13.0
Crude protein	(g/kg)	130	170	160	220	180	140
Lysine	(g/kg)	4.5	8.0	7.0	13.6	10.4	6.6
Methionine/Cystine	(g/kg)	3.1	4.4	3.8	6.8	5.2	5.3
Threonine	(g/kg)	3.8	5.6	4.9	8.2	6.3	4.0
Tryptophan	(g/kg)	0.7	1.5	1.3	1.9	1.5	1.0
Calcium	(g/kg)	8.5	8.5	8.5	9.8	8.1	7.8
Phosphorus	(g/kg)	6.5	6.5	6.5	7.0	6.1	5.9
Salt (NaCl)	(g/kg)	3.0	3.0	3.0	3.2	3.1	3.0
Iron	(mg/kg)	60.0	60.0	60.0	62.0	59.0	57.0
Zinc	(mg/kg)	50.0	50.0	50.0	56.0	49.0	47.0
Manganese	(mg/kg)	16.0	16.0	16.0	11.0	11.0	11.0
Iodine	(mg/kg)	0.5	0.5	0.5	0.15	0.15	0.15
Selenium	(mg/kg)	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin A	(IU/kg)	8000	8000	8000	8000	6000	6000
Vitamin D	(IU/kg)	1000	1000	1000	1000	750	750
Vitamin E	(IU/kg)	15	15	15	15	15	15
Riboflavin	(mg/kg)	3.0	3.0	3.0	3.0	3.0	3.0
Pantothenic acid	(mg/kg)	10.0	10.0	10.0	10.0	10.0	10.0
Vitamin B12	(mg/kg)	0.015	0.015	0.015	0.01	0.01	0.01
Biotin	(mg/kg)	0.30	0.30	0.30	0.2	0.2	0.2

a Assuming an average litter size of nine piglets. Only feed quantity varies with the number of piglets in the litter.
b Assuming a growth rate of 0.7 kg/day.

approximately 90% of the energy feeding value of maize, it should be ground before use, and can be used at a high level in rations.

Corn and Cob Meal

This is made from the whole maize cob. It has about two-thirds the nutritive value of grain maize with a higher crude fibre content and a lower soluble carbohydrate content. It can be used with advantage in sow and boar rations.

Maize or Corn

Of all cereal grains, maize is one of the richest in carbohydrate and fat. Yellow, but not white, maize is also rich in carotene or provitamin A. It should not be fed alone as its protein content is deficient in certain essential amino acids such as lysine and tryptophan and its phosphorus and nicotinic acid contents are partially unavailable. It can be used at the rate of 85% of the ration for growing pigs and at a somewhat lower rate for pregnant sows. Rations high in maize are said to produce a soft fat. It should be coarsely ground or crushed before feeding. New varieties of maize with higher lysine and other amino acids content have become available for general use in some regions of the tropics. One is known as 'opaque-2'. Others known as quality protein maize (QPM), have been developed and are widely used in west Africa and elsewhere.

Oats

This cereal is not generally available in the tropics, but it may be grown in some montane regions. It has a lower feeding value than maize, partly on account of its relatively high fibre content. No more than 30% of crushed or ground oats should be used in a ration.

Rice

Paddy has a somewhat similar feeding value to wheat, but as the hull has high fibre, lignin and silica, contents, it is not a particularly satisfactory grain feed and its use should never exceed 25% of the total ration although some authorities have suggested that up to 50% can be used.

Rice and/or Wheat Shorts or Middlings

These are by-products of the milling of rice or wheat, but they do not contain hulls. Their energy feeding value may be 90115% that of maize and they may be used at the rate of 60% of the total ration. The rice products are, however, deficient in essential amino acids.

Rice Bran

This is not to be confused with the rice husk. It consists of the outer layers of the rice kernel and contains a high percentage of fat and fibre. It has a somewhat lower feeding value than has wheat bran. It should not be fed at all to piglets, or at more than the rate of 3050% of the total ration to fatteners on account of its high fibre content and laxative effect. In many parts of the monsoonal tropics it is often almost the sole feed available for pigs and as a consequence they grow slowly, develop a soft fat and frequently scour. If large quantities of rice bran have to be fed then the bran should preferably be purchased from old, inefficient mills as their product usually contains varying proportions of broken rice grain.

In some tropical countries paddy is still prepared for cooking by pounding. It should be realized that the rice bran obtained by pounding often has a lower feed value than that obtained by milling as it may sometimes consist of both the rice husk and the outer layers of the rice kernel.

Sorghum.

This cereal possesses approximately 95% of the energy feeding value of maize, with a higher crude protein content. A growingfinishing ration may contain as much as 85% of sorghum, but as it produces a soft fat, it is usual to feed sorghum at the rate of 50% of the total ration. It should be crushed or ground before feeding.

Millet

Like sorghum it should be crushed or ground before feeding but it possesses a lower energy feeding value and should be fed at no more than 35% of the total ration.

Wheat

Wheat is commonly fed to pigs in tropical Australia and in some South American countries and is sometimes available in other montane and/or dry tropical regions. It possesses a feeding value equal or slightly inferior to that of maize. For best results it should not be ground too fine.

Wheat Bran

This feed is often available in tropical countries as wheat-milling complexes have been built at the ports. It has an energy feeding value equivalent to 85% that of maize, but on account of its high fibre content it should only be used in the rations of fatteners and breeding sows. To these classes of pigs it can be fed at the rate of 40% of the ration. Wheat bran is to be preferred to rice bran. All brans are deficient in calcium.

Root Crops

Arrowroot (Maranta spp.*)*

This root can be used in the same way as cassava.

*Queensland Arrowroot (*Synonym: Canna *(Canna edulis))*

This root, containing 2530% dry matter, is used for pig feeding in some Pacific countries and at higher altitudes in some continental tropical regions. It can be fed in the same manner as cassava.

*Cassava (*Synonyms: Tapioca, Manioc, Yuca *(Manihot esculenta))*

Cassava and cassava peelings are both very suitable feeds and pigs fattened on them develop a good, firm fat. This root is widely used for pig feeding in Southeast Asia, Africa, Central and South America. Four parts of the cassava root replace one part of maize meal in pig rations. It is advisable to cook cassava before feeding in order to destroy the poisonous cyanogenetic glucosides found in the skin of many varieties. It can also be used as a silage. In Taiwan cassava and sweet potato silage are used to replace 40% of the grain in pig rations. Dried cassava root or the flour made from it has the same energy feeding value as maize and is widely used as an imported pig feed in Europe. It can be incorporated at the rate of 30% of the total ration. Pigs fed on rice bran can be fed cassava during the last phase of fattening in order to harden their fat.

Potato (Solanum tuberosum)

Potatoes are available in some of the montane and/or dry areas of the tropics. They may be mixed with grain in the ratio of three parts of potato to one of grain. The energy feeding value of this mixture is 30% that of maize. Potatoes may also be dried and made into a flour and this can form up to 30% of the ration.

Sweet Potato (Ipomoea batatas).

Raw sweet potato is unsatisfactory for piglets but can be fed to older pigs. It should be used in the same way as is cassava. In regions where the kidney worm is not a problem, pigs can be allowed in the fields to lift the crop themselves and they will then eat both the tops and the roots. The roots can be processed into a flour that has an energy feeding value equivalent to maize meal and can replace 3550% of the grain in a ration. Like cassava, sweet potato roots can be ensiled.

Taro (Colocasia spp.*)*

The peelings and the whole root are very useful pig feeds that should be used in the same way as is cassava.

Yam (Dioscorea spp.*)*

This root is used in a similar way to taro and cassava. In the tropical world outside the Americas caution should be exercised when feeding the roots of wild yams as some contain toxic substances. The most poisonous species is one found in Malaysia*D. hispida*. It contains an alkaloid known as dioscorine. A common African species, *D. dumetorum*, also contains a toxic alkaloid, as do several others. The roots of these yams can be detoxicated by thorough washing of the sliced roots in water or by cooking.

Miscellaneous Feeds

Cane Molasses

In many tropical countries this was oftenbut may be no longerthe cheapest carbohydrate feed available. Some pigs will eat it readily, others do not like it. It is generally mixed with the meal and can improve the palatability of the ration. It can be used at a rate of up to 20% of the fattening ration, but when more is used it may cause scouring. Young piglets should not receive more than 5% of molasses in their ration. When molasses is combined with a little sugar, feed efficiency is greatly improved. It is characterized by a high level of potassium and molasses diets must be supplemented with salt to ensure a proper sodium/potassium balance.

Citrus Molasses

This feed has approximately the same nutritive value as cane molasses, but as it possesses a bitter taste and is usually unpalatable it can only be used in relatively small quantities in the ration.

Sago (Metroxylon spp.*)*

Five types of feed can be obtained from the sago palm, but only two are suitable for pigs. These are the crude wet sago (representing 40% of the original sago log) and sago flour. Sago flour should not be included in a ration above the 20% level. It tends to produce a pig with a lean carcase and a soft fat. One difficulty in using sago flour is that it often has a rather high moisture content and is consequently difficult to store.

Pigs can be managed to extract the sago from the tree, a feeding practice popular in Borneo. The tree is sawn down at about 78 years of age and cut into logs, each weighing approximately 50 kg. These are then split with an axe and the pigs are allowed access to them.

Sugar

Raw sugar can be used for pig feeding when its cost is comparable to that of other carbohydrate feeds. It can be introduced into piglet rations at the rate of 1020% of the total ration and can probably be fed in larger amounts to older pigs. There are valid reasons for using itat the rate of approximately 5% in baby-pig rationseven when it is more expensive than other carbohydrate feeds. Piglets will start eating a ration containing sugar much earlier than one that does not contain it.

Feeds Containing Mainly Protein

Blood Meal.

Where this feed is available, as it often is in South America, it can be used at the rate of 5% of the ration.

Copra Cake or Meal (Coconut Meal)

This is the meal manufactured from the cake that remains after oil is expressed from dried coconut, commonly known as copra. It normally contains 15% crude fibre and <22% crude protein (CP). It is available in many regions of the tropics and can be used at a maximum rate of 30% of the total ration. As the protein in the meal has an unbalanced amino acid content it should only be used at low levels in the ration of young piglets. It apparently stimulates milk secretion and is very suitable for the feeding of lactating sows. The high concentration of saturated fats in this meal produces a carcase with a firm fat. Copra meal made by the expeller method is more valuable as a feed than that made by the solvent process.

Cottonseed Meal

Undecorticated cotton seed can only be included in pig rations at a very low level. The meal, however, with a CP content of 45% can be used at a rate not exceeding 10%. It is best used mixed 50:50 with peanut meal. The seed and some meals contain a toxic substance known as gossypol that reduces protein utilization. This is one reason for using cottonseed meals at low levels. De-gossypolled meals are available in some countries.

Fish Meal

Apart from the conventional fish meals, whale and shrimp meals are also available in some regions. In many tropical countries there are two types of fish meal on the market, one sun dried and the other artificially dried. Sun-dried fish meal usually has a lower protein content and a higher oil content and it may be dangerously contaminated with bacteria. The amount of fish meal used should never exceed 10% of the ration, and normally a smaller proportion is fed as high levels impart a fishy taste to the pork. It should never be used during the final stage of fattening.

Fish Silage

In countries where fluctuations in the supply of waste fish make the production of fish meal commercially unattractive, fermented or acid silage fish products can be made and fed to pigs.

Linseed Meal

This meal should not be used at the rate of more than 5% of the total ration.

Maize (Corn) By-Products

Corn germ meal, corn gluten meal and dried corn distillers' solubles have a reasonably high feed value and the latter is a valuable source of B-complex vitamins. The protein of corn germ meal is of a better quality than that of corn gluten meal or corn gluten feed. These by-products are best used in combination with other feeds and their use in a ration should not exceed 5% of the total.

Meat and Meat and Bone Meals

The quality of meat meal varies considerably as many so-called meat meals are really meat and bone meals. If either meal is available at an economic price it can be used at the rate of 510% of the total ration. The emergence of the disease bovine spongiform encephalopathy (BSE), however, has raised questions as to the wisdom of feeding meat and meat and bone meal.

Milk and Milk By-Products

Buttermilk and/or separated milk are sometimes available in regions where there are milk-processing factories. A ration containing buttermilk or separated milk and cassava or maize is a very satisfactory rearing and fattening ration. It is only economic to use skim-milk powder in baby-pig starter rations at levels varying from 10 to 30% of the total ration.

Peanut Meal (Synonym: Groundnut Cake).

Although peanut meal is a very useful protein concentrate it is deficient in methionine and care must be taken in its use because of the possibility that it may be contaminated with a fungus (*Aspergillus flavus*) that produces toxic materials known as aflatoxins. Meals with more than 1.0 ppm aflatoxin should not be fed to fattening pigs. Those with 0.51.0 ppm should not be fed to young pigs and breeding sows. This meal also goes rancid if it is stored for a long period.

Safflower (Carthamus tinctorius) Meal

The utility of this meal is very limited and it should only be used in very small quantities.

Sesame (Synonym: Sim-Sim *(Sesamum indicum)* Meal)

This meal is used to some extent, particularly in South America, and it can be included at the rate of 25% in the total ration.

Soybean Meal

If it is available this is the bestquality plant protein feed available for young growing piglets and brood sows. Solvent extracted is of better quality than expeller processed meal. Raw beans should not be used as they contain a trypsin inhibitor that is destroyed during processing.

Yeast

This is an excellent protein concentrate and a very rich source of the vitamin B complex. It can be fed at the rate of 3% of the total ration. Live yeast must be killed by cooking before it is fed, or it may cause scouring.

Miscellaneous Feeds

Avocado Pear (Persea americana)

Small amounts of waste avocado pears can be fed to pigs. Three parts of avocado replace one part of maize in the ration.

Bananas and Plantains (Musa spp.*)*

Green and overripe bananas can be fed to pigs as a source of energy. They are more palatable when they are overripe. Waste green bananas from packing stations should be cooked before feeding and can be ensiled. Plantains are equally useful. Three parts of overripe bananas replace one part of maize and investigators in Latin America have reported that bananas can replace 2030% of maize in a ration. Banana meal made from dried bananas can be used at a level of 2540% in growing-finishing rations and in rations for gestating sows. The CP content of banana meal is very low. Finely chopped banana stems are a major part of the ration for pigs in some parts of Southeast Asia and China.

Breadfruit (Artocarpus altilis)

This fruit is fed in a similar manner to cassava, yam and taro.

Brewers' and Distillers' Grains.

Both products can be used for feeding fattening pigs over 45 kg liveweight. Distillers' grains have a slightly higher feeding value. Wet grains must be ensiled unless they can be fed immediately after production. They should not constitute more than one-third of the diet.

Citrus Fruit

Pigs will eat waste citrus fruits but they do not thrive on them, although it is safe to feed small quantities.

Cocoa Meal

This meal is not suitable for pig feeding.

Fermented Feeds

Many by-product feeds such as corn cobs, rice bran and banana stems as well as seaweed can be fermented before feeding. Fermented feeds alone do not apparently exercise beneficial effects on liveweight gain and feed efficiency, but they are very palatable and when mixed with other feeds improve feed consumption.

Forage

It is difficult to manage pigs on pasture in the humid tropics on account of the internal parasite problem. Pigs do, however, benefit from receiving green forage even when fed complete concentrate rations indoors. Adult pigs may be given up to 4.5 kg per day unless they are fed rations containing a grass or legume meal. Guinea, para and elephant grasses are all suitable as are banana stems, cassava (not all varieties) and sweet-potato tops, browse plants such as *Sesbania grandiflora* and water plants such as *Ipomoea aquatica*. In Southeast Asia a meal made from dried leaves of the legume *Leucaena leucocephala* is often added to mixed feeds. The feeding rate should not exceed 5% of the total ration.

Green Copra

Although green copra is usually too expensive to feed to pigs it is sometimes used in coconut-growing areas. It produces a soft fat and should not form too large a proportion of any ration.

Papaya (Carica spp.*)*

Small quantities of papaya are an excellent feed for pigs. If fed at the rate of 25% of the ration five parts of papaya replace one part of maize meal.

Pineapple Bran

This is the dried outer flesh and core of the pineapple. It is very fibrous and should not be fed to pigs until they weigh more than 45 kg, and then only in small quantities.

Pumpkins

Pumpkins are a useful feed, seven to nine parts of pumpkin replacing one part of maize in the ration.

Ramie (Boehmeria nivea).

When ramie is immature it is not fibrous and it is an excellent, succulent pig feed.

Sugar Cane

Can be fed as part of the forage component of the ration. It is only suitable as a green feed when it is young.

Tomato

Waste tomatoes should only be fed in small quantities at the rate of ten parts for one part of maize.

Additives

Apart from vitamin and mineral mixes and green feed when available, a number of additives to pig rations have been advocated. Only the following are considered to be of value to the tropical pig farmer.

Antibiotics

The addition of a small amount of antibiotics to pig rations usually results in an improvement in the rate of liveweight gain and in the efficiency of feed conversion, but has no effect on carcase quality. These improvements are most marked where the protein in the ration is derived solely from plant sources, and the feeding of a ration containing antibiotics may have a particularly beneficial effect on the growth of runt pigs. There is no benefit to be obtained from feeding antibiotics to pigs which are receiving large amount of skim-milk or buttermilk. Recommended levels of antibiotics in rations are given in Table 14.6.

Table 14.6 Recommended levels (g/t of complete feed) of antibiotic and copper in pig rations. (*Source*: Durrance, 1971.)

	Piglets	Growers	Finishers
Antibiotica	<40	1020	10
Copper compounds			
Cupric carbonate ($CuCO_3$)	250	250	
Cupric oxide (CuO)	160	160	
Cupric sulphate ($CuSO_4 \cdot 5H_2O$)	500	500	

a Aureomycin, bacitracin and terramycin are probably the most useful but some others may be used.

Copper

This is of course an essential mineral nutrient, being necessary for haematopoiesis, but under certain circumstances the addition of copper over and above normal nutrient needs to pig rations improves rate of gain and feed efficiency. The farmer must always remember that copper is toxic when fed in excess and that a safe level in rations is considered to be no more than 125 parts of copper per million parts of feed. Recommended levels of copper that may be added to the ration of growers are shown in Table 14.6. The farmer should remember when feeding additional copper to his pigs that the excretion of additional quantities of this element may interfere with beneficial bacterial action in pig effluent-disposal systems.

Choline

This micronutrient is almost completely absent from maize and the addition of 0.1 g of choline per kg improves maize-based rations.

Synthetic Amino Acids

A ration containing a high proportion of oil-seed feeds can be improved by the addition of up to 0.5% of synthetic methionine. The addition of synthetic lysine can also have advantages in many rations, but if blood meal is available this feed can be used at the rate of 3% of the total ration to increase the lysine content of the ration.

In general, these additives will produce the best response in pigs weighing less than 35 kg. There is evidence, however, that when antibiotics are omitted from the diet of older pigs that received them at a younger age, then the rate of gain of the pigs is reduced and if antibiotics are to be used it is necessary to feed them throughout the fattening period.

Readers should note that the use of additives in livestock rations is controlled by legislation in many countries.

Preparation of Feeds

It is usually neither desirable nor necessary to process all feeds for pigs, but there are some important exceptions to this rule.

The mixing of rations is a time-consuming operation, but often in the tropics has to be carried out by the farmer as there are too few feed-processing firms. The pig farmer should plan his feed store in such a way as to use the minimum of labour, and the installation of modern mixing machinery should be considered by the larger pig farmer as many types of mixer suitable for farm operations are now available.

Milling.

All cereal grains should be coarsely ground or cracked, as should grain legumes. Coarse grades of protein concentrate feeds such as coconut cake should also be ground for use in self-feeders. Grinding increases the food value of the grains by some 20%, but feeds should not be ground too fine as this reduces palatability, increases the possibility of the meal becoming caked and, in addition, finely ground grain does not run so well in a self-feeder.

Soaking

This practice does not improve the food value or the palatability of feeds and it is impossible to feed soaked feed in a self-feeder or in automatic feeding systems. There may, however, be something to be said for the dampening of a dry-feed mixture that is hand fed, particularly if the mixture contains a high proportion of coconut meal. If molasses is fed it can be used to dampen the feed mixture. There is no value in feeding a sloppy feed mix unless a supply of fresh water is not available in the pen.

Cooking

This does not usually improve the food value of feeds, but it is essential to boil or pasteurize skim-milk or buttermilk from cows that may be infected with tuberculosis. All slaughterhouse offals and swill must be boiled for 30 minutes in order to kill any pathogenic organisms that they might harbour. It is general experience that all roots and root peelings are better fed cooked than raw as they are slightly more digestible when they are cooked. There is a special reason for cooking cassava or cassava peelings as this destroys the poisonous substances that are found in the skin of some varieties. Cooked tapioca packed in a pit makes good silage that keeps for many months and is always relished by pigs. Sweet potato, green bananas and many legume seeds are more easily digested after cooking.

Methods of Calculating Rations

Pigs require different rations at different stages of life. As the pig grows older, protein, mineral and vitamin requirements decrease. Animal protein, in particular, is more essential for the young than for the older animal, and the ability of the pig to deal with roughage increases with age. The most expensive ration is required for the suckling pig.

Theoretically, pigs require the following types of ration:

- A relatively expensive ration for creep feeding suckling pigs up to 7 weeks of age that should contain 1920% CPa large proportion of which should be of animal origin. The mineral and vitamin content of this ration should be high, the fibre content low and the ration should be very palatable. If it is desired to early-wean piglets a ration with an even higher CP content of 2022% should be fed and the piglets weaned on to the creep feeding ration or on to a starter ration.

• A starter ration for weaned pigs. This should contain 18% CP, a low fibre content and be highly digestible. It may be fed until the pigs are 1423 kg liveweight.

• A grower ration with approximately 16% CP, preferably still containing some protein of animal origin, still very palatable and with some fibre. This is fed to pigs weighing 2355 kg.

• A fattening ration containing 14% CP, none of which need be of animal origin for pigs weighing 4590 kg.

• A ration for gestating females that can be of relatively coarse texture. The ration for gilts should contain 16% CP, while that for sows should contain 14% CP during the final months of gestation.

• A ration for lactating females that should contain 16% CP.

• Rations for young boars less than 15 months of age containing 16% CP and for older boars containing 14% CP.

In practice it is usually possible to reduce the number of different rations used by combining two or more of the above types to substitute for one of the others.

In some tropical countries a majority of pig producers now purchase pig feeds from livestock feed companies. These companies use computers and tables of the nutritive value of feeds to formulate least cost rations from available feeds and advise farmers as to which ration to use for each class of stock. Farmers can also formulate and mix their own rations using similar techniques now that microcomputers are relatively cheap and freely available. Readers should consult any modern textbook on pig production for details of the formulation techniques.

There are still, however, very many farmers rearing pigs in the tropics without access to commercial feeds or to computers and information on nutrition. These require some simple 'rule of thumb' method of pig feeding. If a local extension agent or adviser can provide farmers with information as to the nutritive ratio (i.e. the ratio of protein to carbohydrate feed constituents) and the maize meal energy equivalent of locally available feeds, then using the data provided in Table 14.7 farmers can formulate suitable rations from available feeds. They will, in addition to the mixture of protein and carbohydrate feeds, require adequate mineral and vitamin supplements and the provision of these is considered below. Farmers should be able to test the utility of their rations by comparing the growth of their pigs with the expected gain data provided in Table 14.7 or the expected liveweight for age data given in Table 14.8.

Farmers cannot be expected to mix their own mineral and vitamin supplements as they do not usually possess the equipment or, normally, have the technical competence. These supplements can be purchased as a premix from reliable feed merchants in most tropical countries. Instructions as to the quantity of premix that should be added to different types of ration should be provided by the supplier.

If vitamin and mineral premixes are not available the farmer should see that all classes of his pigs receive some fresh succulent forage daily and a simple mineral mixture may be made up on the farm by mixing 60% ground sea shell with 30% bone meal and 10% iodinized salt. This latter mixture should be added to all rations at the rate of 3 kg per 100 kg of ration. A little fresh soil or grass sod may also be placed in the pens daily if it is thought that the pigs may suffer from an unknown trace-element deficiency.

Finally, the farmer must ensure that not only is the nutritive ratio, the nutrient content of the feed and the amount of feed fed approximately correct, but that his pigs are receiving adequate quantities of water and that the feeds do not contain too much fibre or any toxic materials. Some details of the approximate water requirements of different classes of pigs in the tropics are given in Table 14.9. If it is possible, automatic watering devices should be installed. The farmer should also remember that rapid growth up to 50 kg will encourage the formation of muscular tissue, but that beyond this liveweight too rapid a

Table 14.7 Essential data required for the calculation of rations for pigs and for assessment of their performance. (*Source*: Based on Durrance, 1971.)

Class and liveweight of pigs (kg)	Nutritive ratio required in the ration	Average daily feed intake (kg)	Expected average daily liveweight gain (kg)
Piglets (Birth to 14)			
Creep feed for early weaners Creep feed for normal weaners	1.0:4.04.5	0.140.7	0.32
Weaners (1423)			
Starter rations	1.0:4.5	0.71.4	0.29
Growers (2354)	1.0:4.55.5		0.64
25		1.4	
32		1.8	
41		2.0	
Fatteners (4591)	1.0:5.57.0		0.84
45		2.5	
59		2.5	
68		2.52.7	
Pregnant gilts and sows	1.0:5.0	2.3	
Suckling gilts and sows	1.0:5.0	5.4 or 0.9 plus 0.5 for each suckling pig	
Boars	1.0:5.0		
<15 months of age		2.7	
>15 months of age		2.3	

Table 14.8 Expected liveweight for age under good average feeding and managerial conditions.

Age (week)	Liveweight (kg)
3	5
8	14
10	19
12	24
15	37
20	54
24	72

28	90

growth will encourage the formation of fat. Restricted feeding is usually necessary to limit fatness.

Pigs are creatures of habit and it is essential that they should be fed regularly. It is also important that the changeover from one ration to another should be accomplished gradually.

The number of different rations that can be compounded is infinite as there are so many different feeds available in different countries. Consequently, no attempt is made here to evaluate typical rations for different classes of pigs. Further details on specific feeding practices for different classes of pigs are provided in the management section.

Health

One of the major problems confronting pig producers in the tropics, particularly in the humid regions, is the high mortality rate. For example, it has been reported from the Philippines that the mortality rate from birth to maturity is approximately 50%. Even in countries such as Fiji

Table 14.9 Approximate water requirements of pigs in the tropics.

Class of pig	Approximate water requirements per day (litres)
Growing pigs (weeks of age)	
812	3.5
1318	6.0
1924	7.5
25	8.0
Pregnant gilts and sows	
First 3 months	1015
Last months	1620
Lactating sows with:	
57 piglets	2025
810 piglets	2227
1124 piglets	2835
Boars	2025

If water is also used for cleaning and mist spraying, requirements will be double those given in the table.

where there are no major epizootic diseases, mortality rates in the local pig population have been as high as 30%. A very brief mention of some of the major causes of ill-health of pigs in the tropics is provided below, but for details of pig diseases and parasites and their control readers should consult a tropical veterinary reference book such as Hall (1985) and/or their local veterinary authority.

Disease

Some diseases such as brucellosis, leptospirosis, metritis, mastitis and agalactia are found mainly in breeding stock. Brucellosis and leptospirosis may be the cause of abortion or the birth of weak piglets, etc. These two diseases, as well as metritis, also cause sterility. Mastitis and agalactia are difficult to control, result in weak piglets and increase piglet mortality.

Other diseases, such as transmittable gastroenteritis (TGE) and swine influenza, mainly affect younger pigs. The incidence of TGE is sporadic, but in infected pigs mortality can be very high. Swine influenza is very contagious, but most infected piglets recover unless they contract a secondary infection such as bronchopneumonia.

Diseases, such as hog cholera (swine fever) or African swine fever (ASF) and swine plague, attack pigs of all ages. Hog cholera, caused by a virus, is the most serious pig disease in the Americas and Southeast Asia. It can be controlled by proper vaccination. African swine fever, caused by a very similar but immunologically distinct virus, is of equal importance in Africa and is now spreading outside that continent. There is no satisfactory vaccine against ASF. Swine plague is a major disease in Southeast Asia when pigs are subject to any form of stress.

External Parasites

Pigs in the tropics suffer badly from mange caused by the mite. *Sarcoptes scabiei* var. *suis*. It is extremely contagious and infected pigs should be treated as quickly as possible. Organophosphorus compounds applied as a bath, a shower, or brushed into the skin are effective but care should be taken in their use as they are dangerous. In some countries their use is prohibited. The other external parasite of importance in pigs is the pig louse, *Haematopinus suis*. Apart from causing acute discomfort to the pig this louse transmits swine pox virus and possibly swine fever. It can be controlled by brushing the affected areas of the skin with a mixture of kerosene and lard or some other fat or oil or even with used engine oil. After treatment pigs should be kept out of sunlight for at least 48 hours.

Internal Parasites

These are the cause of considerable mortality, lack of vigour and unthriftiness, particularly in young pigs. The most important internal parasites are the intestinal roundworms such as *Ascaris lumbricoides* var. *suis* and the kidney worm *Stephanurus dentatus*, but lungworms (*Metastrongylus* spp.), nodular worms (*Oesophagostomum* spp.), threadworms (*Strongyloides*) and whip worms (*Trichuris* spp.) also take their toll. Generally, all can be controlled by the use of the most effective anthelmintics, proper sty cleaning and good hygiene. Piperazine is effective against ascarids and thiabendazole and tetramisole against a wider range of worms. All pigs entering the herd should be treated as should piglets and sows immediately after weaning, fattening pigs at about 4 months of age and boars at 6-month intervals.

The kidney worm is of particular interest to the pig farmer as its presence in a region dictates managerial practice. Infected pigs are anaemic, grow slowly and are stunted. The adult worm lives in the kidney or in the walls of the ureters. Eggs are passed in the urine to the soil and if conditions are suitable (at least 28°C temperature and 90% humidity) infectious larvae are produced. These may be ingested by foraging pigs, but can survive in the soil for long periods. The only sure method of reducing kidney worm infection is to remove pigs from contact with the soil for relatively long periods. Thus in most regions of the humid tropics good husbandry dictates that pigs are managed indoors on floors that can be easily and properly cleaned.

Cysticerosis is the parasitism of pigs by Cysticerci, the larval form of the tapeworm (*Taenia solium*), unique to humans, dogs and cats. Pigs are contaminated by consuming the tapeworm eggs in human excrement. Humans are infected from the Cysticerci by eating improperly cooked, contaminated pig meat. The infective cycle can be broken by penning pigs, keeping dogs and cats under control, the hygienic disposal of human excrement and thorough cooking of pig meat.

Trichinosis is caused by the nematode *Trichinella spiralis*, an internal parasite of pigs that can affect humans. To break the cycle all garbage fed to pigs should be properly cooked and humans should not eat uncooked pig meat.

Other Causes of Ill-Health and Death

These are many: the direct effect of tropical climates, including heart attack in mature pigs and photosensitization in white-skinned breeds; nutritional disorders dealt with in a previous section and the ingestion of pollutants and poisons as pigs are omnivorous and greedy feeders; hypoglycaemia in very young pigs; and lameness in, and overcrowding of, penned pigs. In addition, a large number of piglets are lost at birth due to 'overlaying' by the sow (Table 14.10).

Control Measures.

The most effective control measure is preventive action. As stressed pigs are more likely to succumb to disease and parasites, the most effective preventive action is to reduce nutritional, climatic and other environmental stresses to a minimum by good management. Some other measures that can be taken are:

• The use of vaccination in those cases where vaccines are available and effective.

Table 14.10 The cause of death of piglets in an experimental herd in Fiji.

Cause of death	Breed				All breeds	
	Tamworth	Berkshire	Large White	Crossbreds	Total	As % of total
Stillbirth	8	7	9	8	32	17.4
Eaten by sow		1			1	0.5
Genetic defect	2			1	3	1.6
Overlaid	7	20	83	12	122	66.3
Enteritis	1			3	4	2.2
Pneumonia		1			1	0.5
Unknown		8		13	21	11.5
Totals	18	37	92	37	184	100.0

- The control of external and internal parasites by spraying and/or drenching when necessary (see section on management).

- Adequate feeding at all stages and the amelioration of climatic stress by the provision of suitable housing.

- The segregation of individual diseased animals and premises when outbreaks of disease occur.

- The proper disposal of diseased pigs, by slaughter if necessary, and of infective material by burning or other suitable means.

- The cleaning and disinfection of all premises and equipment after an outbreak of disease and no re-use of the premises for 3 or 4 weeks.

Management

Successful management of pigs in any part of the world depends primarily on intelligent planning that is based on a knowledge of the biology of the pig.

In most tropical countries in the past, the indigenous producers did not attempt to obtain maximum productivity from their pigs but managed them primarily as scavengers. Although pigs are still used as scavengers, in most countries there is also an ever-expanding commercial pig industry. Methods of management in this new commercial sector should not necessarily be based on those now practised in the temperate zone.

Adaptive Physiology

The pig is essentially a non-sweating species and is very sensitive to changes in the climatic environment. While discussing the origin of our present major breeds it was suggested that the majority of the pigs managed in the tropical world today are derived from the wild species of Eurasia. Thus, modern pig breeds are derived, at least in part, from wild species adapted to a warm, shaded, humid environment. These facts probably explain why temperate-type breeds of pigs, unlike temperate-type breeds of cattle, thrive in the humid tropics under suitable managerial and feeding conditions. The following facts have been established with regard to the effect of ambient temperature on pigs.

The baby piglet at birth does not appear to possess a very efficient temperature-regulating mechanism. It is incapable of protecting itself against either excessive heat or cold. Newland *et al*. (1952) have shown that the body temperature of the baby pig of typical American breeding falls 1.7°C to 7.2°C during the first 30 minutes of life and then slowly returns to normal during the next 48 hours. The body temperature falls most rapidly in small piglets that weigh under 0.9 kg and takes a longer time to recover to normal if the air temperature is low. These workers suggested that cold air temperatures contribute to an increase in the mortality of piglets during the first 2 or 3 days of life, particularly as chilled piglets stand and shiver, become sluggish in their movements and are likely to be more easily 'laidon' by their mother. Later work has confirmed these suggestions, and in practice during the first 2 days of life the ambient temperature for piglets should exceed 32°C and be gradually lowered as the piglets age. It is now normal practice in temperate-zone countries to use infra-red lamps to warm the piglets immediately after birth, so that they do not get chilled. This managerial practice unquestionably reduces piglet mortality. In the tropics where mean annual air temperatures vary around 27°C the problem is not so acute as it is in the temperate climatic zone. However, it has been found that even in a tropical climate piglet mortality due to overlaying may be reduced by the use of an additional heat source for the baby piglets during the first few days of life.

As pigs age and grow the optimal ambient temperature for maximum liveweight gain and efficiency of food conversion changes. Heitman & Hughes (1949) raised pigs in a controlled climatic chamber for periods averaging 7 days in air temperatures ranging from 4.4° to 46°C at a comparatively constant relative humidity and airflow. They found (Fig. 14.7) that liveweight gain and efficiency of food conversion was at a maximum at approximately 24°C for pigs weighing 3265 kg and at approximately 15.6°C for pigs weighing 75118 kg. They also noted that if the air temperature rose the respiration rate of pigs

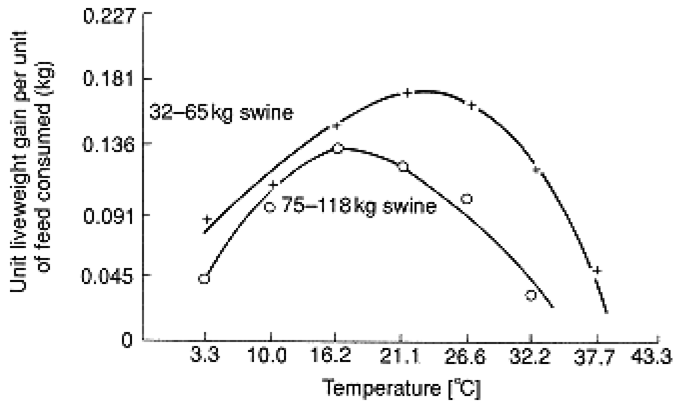

Fig. 14.7
The effect of ambient temperature on the efficiency of food conversion in pigs.
(Source: Heitman & Hughes, 1949.)

also rose very rapidly. Other American workers have shown that at temperatures of 32.2°C and above, respiration rates of 150200 per minute are common in pigs. Under these circumstances the pigs stop eating and lose weight, and if forced to exercise may even die of heat exhaustion. The general observations of Heitman & Hughes (1949) have been confirmed by other investigators. Serres (1992) has recently confirmed the drastic effect that high ambient temperature has on the daily liveweight gain of pigs weighing more than 45 kg (Table 14.11). Verstegen *et al*. (1973) have shown that although energy retention in the pig depends upon ambient temperature and feeding level, nitrogen retention is not influenced by ambient temperature.

Mean annual temperatures in most regions of the tropics are only 35°C above 24°C, so that tropical pigs weighing 3265 kg are probably being reared under almost optimal environmental conditions, but as pigs grow older and heavier normal tropical temperatures would be too high for maximum productivity. Thus, in the tropics, the aim should be to raise a porker weighing approximately 5464 kg and not bacon or lard pigs weighing 91109 kg.

During the daytime, particularly during the hottest months, tropical ambient temperatures are usually well above 24°C and the larger fatteners, as well as the gilts, sows and boars, may require some amelioration of the climatic stress if they are to produce at a maximum. Under such conditions relief from the adverse climatic conditions can be obtained by the provision of ad

Table 14.11 Effect of ambient temperature on the daily liveweight gain of pigs fed *ad libitum.*
(Source: Serres, 1992.)

Liveweight	Ambient Temperature °C		
(kg)	21	27	32
	Daily Liveweight gain (kg)		
45	0.91	0.89	0.64
70	0.98	0.83	0.52
90	1.01	0.76	0.40
115	0.97	0.68	0.28
135	0.93	0.62	0.16
160	0.90	0.55	0.05

equate shade and fine water sprays or wallows. For adequate shade the roof of the pig pen should not be too low and should preferably be constructed of thatch (unless vermin are a major nuisance) or tile; if it is necessary to use corrugated iron then the roof should be painted black on the underside with aluminium paint on the top surface. The importance of shelter is shown by pig management studies in South Australia where maximum summer temperatures may be as high as 40°C. Under these conditions, pigs housed inside and those managed outside with wallows and shelter grew significantly faster than those managed outside with wallows but no shelter (Stone & Heap, 1982). The most suitable site for water sprays is in the dunging passage, if the buildings are provided with such a facility. Wallows should be approximately 25 cm deep with a surface area of approximately 1.5 m2 per sow and should preferably be covered with a roof. Wallows should be constructed so that the water in them can easily be changed as they rapidly become very dirty. If energy is relatively cheap and engineering skill available an alternate cooling device that has been advocated is a forced cool-air draught. This can be particularly useful for cooling the sow in a farrowing pen when the young piglets require a relatively high ambient temperature, whereas the sow, if she is to milk adequately, requires a lower ambient temperature. Under the restricted conditions of a farrowing pen a forced cool-air draught can be directed on to the head of the sow and some relief can be provided for her without radically reducing the overall ambient temperature within the pen.

There is limited information on the effect of high temperature on carcase characteristics. In two experiments Holmes (1971) compared the carcase characteristics of a group of Large White and Landrace pigs raised at 3132°C and 3233°C with a group raised at 2124°C and 2226°C. Carcase length (one experiment) and backfat thickness (both experiments) were significantly greater in the heat-stressed group and the weight of the liver was significantly less (one experiment). On the other hand, Stone & Heap (1982) noted that pigs raised out of doors without shelter, when maximum ambient temperatures were of the order of 40°C, possessed a significantly higher dressing out percentage and less backfat than pigs raised indoors. Serres (1992) has stated that more recent work suggests that carcase quality is not significantly affected by high ambient temperatures and that the latter never favours excessive fattening.

It may be thought that pigs in the tropics can be properly managed either in or out of doors and that it might be less expensive to provide adequate shade and wallows out of doors. Unfortunately, there is one major difficulty experienced in managing pigs outdoors and that is the very high incidence of certain internal parasites. This is particularly so in the humid tropics which provide an almost perfect environment for many parasites. The most dangerous of these is the kidney worm (*Stephanurus dentatus*), and in many regions the population of this parasite is so high that pigs can only be managed properly on floors that can be cleaned daily. Even a very strict rotation of pigs around a series of outdoor paddocks is an inadequate precaution. Pig breeds do vary in their tolerance of a high incidence of kidney worm infection and some indigenous Southeast Asian breeds appear to be considerably more tolerant than do breeds originating from the temperate zone.

Systems of Management

These may be conveniently classified into those suitable for the subsistence or semi-subsistence peasant or village producer and those that can only be practised by commercial producers.

The Peasant or Village Producer

In most villages, in regions where pigs are kept as domestic livestock, there are pigs that are free to roam where they will. They are useful as scavengers, sometimes cleaning up human and domestic animal faeces and always picking up food offals where they can.

Quite simple arrangements could be made to improve the productivity of scavenging village pigs. Some of these are:

(1) The feeding of supplementary feeds, either once or twice a day. In an area adjacent to the house the pigs could be fed waste feed, such as rice bran and the peelings of root crops. If the householder is willing to cook the waste feeds so much the better. This is a system that is widely practised by the Dayak people of Sarawak, who boil roots and green leaves and pour the hot mixture over rice bran spread on the bottom of wooden troughs. The greatest difficulty encountered is that of keeping neighbouring pigs away from the feed.

(2) Where land is plentiful the pigs can be managed in simply fenced paddocks adjacent to the household in which root crops are grown and into which all household offals are

thrown and where the cooked feeds can be fed secure from neighbouring pigs. The fences might be made of netting wire, if this is available at an economic price, or they can be made of plaited bamboo, paling wood or a closely planted live-fence species. The paddock should be subdivided into four to six smaller areas so that the pigs can be moved from one enclosure to another at 10-day to 2-week intervals, thus reducing the incidence of parasitic infection. Water and shade would have to be available within the paddock. Pigs raised in this manner might not, in the first place, be very much more productive than scavenger pigs, but females could be bred to selected sires so that the stock could be slowly improved. This method could not be used in regions where the incidence of kidney worm infestation is high.

(3) A further improvement would be to construct simple pens in which pigs could be confined. Productivity would, of course, only be improved if there was sufficient food available from village resources to feed the confined pigs and if they were regularly fed and watered. Several types of simple pen can be constructed and one of the authors has seen and inspected many different types used in different regions of the tropics. Some suitable types are:

(a) A simple deep litter pen. This could be constructed of rough timber with a thatch roof and an earth floor. Coarse hay, straw, rice hulls, reed, etc., can be thrown continuously into the pen in order to create a suitable type of litter. It would be necessary to construct such a pen on a well-drained site.

(b) A conventional pen with a concrete floor that can be washed or cleaned in some other manner. The pen could be constructed of rough timber with a thatch roof. If it was built close to a stream that was not otherwise used by humans, water could be diverted to run through it. This running water could be used both for drinking purposes and for cleaning the pens.

(c) A timber pen with a thatch roof could be built with a raised slatted bamboo floor, either over a fish pond or over a drainage channel. This is a type of simple and practical pig pen that is often used in Southeast Asia.

(4) Still further improvements could be effected by the distribution of improved sires for upgrading purposes and by the provision of high protein and mineral feed supplements. In any upgrading programme great care must be taken not to upgrade too quickly or too far. The feeds available to the average villager are not usually suitable for the proper feeding of high-grade exotic pigs, although increases in productivity may be achieved by the use of first-cross exotic sires. The possible use of high-protein and mineral supplements depends upon whether the farmer has a sufficiently high cash income to afford to purchase supplements and/or the availability of such supplements.

(5) There is of course no reason, circumstances permitting, why the village pig-keeper should not be encouraged to use some of the more advanced managerial practices described below. The suggested managerial improvements described above are only considered as useful first steps in the raising of the general level of management of pigs in the village.

The Commercial Producer

The managerial methods used will depend upon what labour and feed supplies are available and at what cost, and on the incidence of disease and parasites.

The total number of commercial pig farms in the tropics has been increasing rapidly in recent years, particularly in Southeast Asian countries such as the Philippines, Singapore, Malaysia and Thailand. Despite these developments many pigs in the tropics are still managed under village subsistence conditions, although the proportion of the total pig population managed by commercial producers is likely to continue to increase.

Accompanying this increase in large-scale operations, there has been increasing specialization and development of the use of ever-increasing quantities of commercial prepared feeds. Nevertheless, the pig industry still depends mainly upon continuous and large supplies of by-product feeds, the difference being that a considerable proportion of these by-product feeds are now incorporated into commercial feed mixes. This is a highly desirable development as available by-product feeds will, in general, be used more economically.

Commercial pig production is therefore likely to develop in those regions of the tropics where ample supplies of by-product feeds are available and where there is a large consumer demand for pork. Southeast Asia is one such region. Not only are there very large quantities of rice-milling by-products available, but wheat by-products are also now available from new mills sited at the ports and maize by-products from new processing plants. In addition, a variety of high-protein meals are produced, such as coconut, sesame, peanut, cottonseed, rubber and oil palm, and there are expanding fishmeal and abattoir by-product industries.

Despite increasing specialization within the industry, the large-scale breeding of purebred lines and/or hybrid pigs for use by the commercial sector is only now developing in most tropical countries, and the government is often still the only major source of supply of breeding stock and crossbred pigs. It is therefore usual for the large-scale pig farmer to raise the majority of his own breeding stock. In order to do this he will need accommodation for farrowing, creep feeding and fattening and for in-pig gilts and sows, boars and young breeding stock. He will also probably require feed-milling and mixing equipment, storage for straight and mixed feeds, weighing facilities, loading places, a piped water supply and facilities for the removal of manure.

Intensive Systems

All pigs should be raised on concrete floors or on some other form of flooring, such as one made of slats, that can be cleaned daily. This should ensure that internal parasites can be adequately controlled and that labour costs are reduced to a minimum. Concrete floors should not be too smooth or the pigs may skid on them, nor should they be too rough. Litter may or may not be used according to circumstances. If a slatted floor is favoured the slats may extend over the dunging passage or cover the entire area of the pen. The latter is more expensive but preferable. The slats may be made of wood, concrete, steel and/or aluminium and should be spaced sufficiently close so that the pigs do not get their feet trapped. The slat width should be 1013 cm and the space between slats no more than 2.5 cm. If the slats extend over the whole pen there is no need to provide a dunging passage. The space below the slat should slope towards a drainage outlet so that dung can be flushed off the slats with water that will drain away. Slats should not normally be used for the floor of farrowing pens. If they are used the slats should be covered with a grating before the sow farrows.

One of the most suitable and cheapest pens is one that is half-covered by a roof so that the pigs can shelter if necessary. The roof should be 2.43 m at the highest point and 1.82.1 m in height at the eaves. It can be made of thatch (coconut frond, nipa, reed, grass, etc.) or of a conventional material such as galvanized iron. A layer of thatch (5 cm) attached by netting wire beneath a galvanized iron roof will improve the microclimate of the pen. Alternatively, as stated earlier, the galvanized iron can be painted black on the underside with aluminium paint on the top side, or aluminium roofing material can be used that is painted black on the underside. The pen can be constructed of any suitable material, but perforated are superior to solid internal walls. Due consideration must be given to both the free circulation of air and the provision of shelter from cold, driving rain.

A simple and very flexible system for the smaller farm is a series of pens that can be adapted for farrowing, fattening or breeding stock, according to the dictates of farm policy. Some difference in the size of pens is desirable as this increases the flexibility of the system. Farrowing pens should be equipped with farrowing rails or a farrowing crate and with creep-feeding facilities. A 2.4 × 4 m pen will accommodate

Table 14.12 Some housing requirements for pigs.

Liveweight (kg)	Area required[a] per pig (m2)	Length of trough required per pig (cm)
1216	0.4	15
1723	0.4	17
2450	0.5	21
5170	0.7	25
71100	0.8	30
>100	1.0	35
Sow	1.5	50
Sow with piglets	10.0	50

a This area excludes feeding and dunging passages.

a sow and her litter, up to 12 porker pigs, eight bacon pigs or three breeding sows.

The larger pig farmer will want to build more specialized housing and some general details on housing requirements are given in Table 14.12.

Feeding troughs should be designed so that the minimum of labour is used for feeding and to prevent feed wastage. They can be fixed or movable and should be made of materials such as sealed concrete, glazed pipe or galvanized iron so that they can easily be cleaned and are not pitted. Feeding troughs finished only in raw concrete will soon be pitted by food acids, particularly if skim-milk is fed. Concrete troughs should therefore be finished inside with a substance that gives a smooth, glazed and permanent finish. There are several such proprietary compounds on the market. Details of the length of feeding troughs required by different classes of pig are given in Table 14.12. If self-feeders are provided, one should provide feeding space for four pigs under, and three pigs over, 15 weeks of age.

Water should be available in all pens for drinking purposes and in all feed alleys for cleaning purposes. The feeding troughs can also be used as water troughs, but pigs tend to lie in them and automatic water cups are preferable if they are available at a reasonable price. One automatic water cup is required in each pen of 2025 pigs. Water should also be available for sprinklers and/or wallows. Drinking water should be as cool as it is possible to provide and water pipes should not be exposed to the hot sun if other arrangements are practicable.

Table 14.13 Approximate daily manure production of pigs.

Age (weeks)	Liveweight (kg)	Volume of solid and liquid manure (litres)
812	1424	1.52.0
1315	2437	2.03.0
1620	3754	3.04.5
2124	5472	4.57.0
2528	7290	7.08.0
Sow with litter		14.0

Bedding may be provided on concrete floors, but is not essential in most tropical environments.

Tree shade over the piggery building is usually desirable if it can be providedwith the exception of buildings in the hurricane zones.

In specialized piggeries all kinds of labour-saving devices can be introduced, including automatic feeders. When planning a piggery it should be ensured that all feedingstuffs and manure move downhill. This can be arranged by siting the feed mixing and/or storage shed at the highest level and the midden or manure-collecting area at the lowest. It should be possible to site the piggery so that manure can be removed with minimum effort. The approximate quantities of manure that may be produced by different classes of pigs are shown in Table 14.13.

Pig manure may be sun-dried and sold as a fertilizer. In some Southeast Asian countries sun-dried manure is a very profitable by-product of the industry. It can also be used for the production of methane gas or for the culture of chlorella. Details of these processes should be obtained from a local agricultural extension officer.

In some areas of Southeast Asia pig farming is associated with fish-pond culture. Effluent from the piggeries is run into fish ponds as it is believed that it improves the growth of microorganisms and plants on which the fish feed. This practice is controversial as often only phosphatic fertilizers are needed in the ponds, nitrogen being fixed very effectively by blue-green algae and potassium being rarely in short supply. Excess effluent nitrogen can in fact be counterproductive as it may inhibit the production of blue-green algae. Also, the organic materials in the effluent may produce deoxygenation in the pond water as they contain carbohydrates that have to be broken down by bacteria which use oxygen dissolved in the water. Nevertheless, large quantities of fish are produced in ponds into which pig effluents flow, particularly in Southeast Asia.

Pig effluent may also be channelled into irrigation canals in order to fertilize fruit or other crops or it may be collected in a sump, filtered and the liquid fraction pumped into an overhead spray irrigation system.

In most temperate-zone countries the disposal of effluents from large-scale piggeries has become a major problem because of the stringent environmental regulations with regard to disposal methods, but in many tropical countries no such regulations have yet been enacted. Farmers should consult their local extension office for information on regulations concerned with the disposal of effluents.

Semi-Intensive Systems

There are many variations of the semi-intensive system. Unfortunately, this system can only be practised in those regions of the tropics where the kidney worm and other internal parasites can be adequately controlled. As the kidney worm parasite takes at least 1 year to grow to maturity within the pig and produces eggs that are voided in the pig's urine, some authorities advocate the management of breeding stock on pasture in regions where there is a low intensity of kidney worm infestation by only retaining gilts to produce three or four litters. The authors do not subscribe to this managerial practice.

Usually breeding pigs are raised outside on grass and fattening pigs are raised intensively in buildings. The most common system is to allow the gilts and the in-pig sows to graze with or without the boars. They must be rotationally grazed around a series of paddocks. These should be located on well-drained soils, low-lying marshy areas being fenced off, provided with adequate shade and a water supply and be well fenced, preferably with pig netting. Mud wallows inevitably become centres of parasite infection and if used they should be frequently cleaned and allowed to dry out in the sun. Sows that root should be nose-ringed.

Sows with litters, housed in portable sheds, can also be rotated across grazings. The shed can be fenced with portable mesh or an electric fence, or alternatively the sow can be tethered. This system is labour intensive as feed and water have to be carried to the pigs, but in regions free of the kidney worm the young pigs are usually very healthy.

Breeding pigs or fatteners can be run in semi-covered yards, fresh litter being thrown into the yard daily. This is a form of deep litter management.

Extensive Systems

All pigs can be put out on grazings or in semi-covered yards. Rotation is essential on grazings and labour costs are high. It is doubtful whether this is a very suitable managerial method in the tropics. One reason is that it needs more supervision and skilled labour than intensive methods, and both are in short supply in most tropical countries. Another reason is possible infestation with kidney worm.

Methods of Management.

Suitable methods of management for the different classes of pigs will be considered in sequence: breeding stock, pregnant gilts and sows, suckling pigs, weaners and fatteners.

Breeding Stock

Young breeding stock should be separated from the remainder of the litter at about 3 months of age. More pigs should be selected for breeding than will be eventually required as it is difficult to decide which animals will be required for breeding at an early age. If breeding stock are purchased, only those with a known history should be accepted. These should be tested for brucellosis and leptospirosis and dewormed before they are imported on to the farm and allowed to mix with other pigs.

All breeding boars and gilts should possess 1214 teats. They should exhibit no obvious inherited defects such as a misshapen jaw and they should be selected from lines that have no history of inherited defects. They should also come from lines that exhibit the characteristics of rapid growth with maximum economy of gain.

Boars and gilts can be reared together until they are approximately 4 months old. They should then be segregated and are best reared out of doors. As this managerial practice is not usually feasible for the reasons discussed in previous sections, they should be fed green feed daily indoors, together with their concentrate rations. Boars of different age and size should not be put together.

Gilts should be first served when they are 78 months of age and weigh 100115 kg. If they are well grown and heavier than 115 kg they can be served at a slightly earlier age. They should not be mated with too large a boar as he may injure them during service. Gilts and sows in oestrus exhibit a swollen, red vulva and are inclined to stand very still when pressure is exerted on their hindquarters. The gilt or sow should be served twice, as explained in the section on reproductive behaviour. Pregnant gilts should not be housed together with pregnant sows.

Boars in the tropics are usually quiet and easily handled. However, they should not be shut up alone or they may develop vicious habits. They are best managed by running together with other boars or with in-pig sows.

The use of boars for service has already been discussed in the section on reproductive behaviour.

As a boar ages, his tusks should be cut off as they can become dangerous.

Pregnant Gilts and Sows

Whatever the system of management, the gilt or sow should be separated from other pigs before farrowing. The approximate date of farrowing should be known as breeding females should be individually mated and accurate records maintained. Gilts will show some signs of udder development after 2 months of pregnancy. Sows normally show signs of new udder development some 2 or 3 weeks before farrowing.

Farrowing

It is good practice to bring the pregnant female into the farrowing pen at least 1 week before she farrows, so that she feels comfortable and at home before parturition occurs. It is also a good practice to deworm the pregnant female, using a mild vermifuge such as piperazine, 1 week before she is brought into the farrowing pen. Pregnant females should also be washed down with soap and a mild antiseptic before they are moved. Some days before farrowing the pregnant female should be provided with some clean litter with which she can build a nest. Long straw is preferable to chopped as the pigs like to chew the litter into small pieces. Although pregnant females should be generously fed during the last 6 weeks of pregnancy, they should not be fed for 24 hours before farrowing.

The farrowing pen should include an area that can be kept dry and within which the pregnant pig can farrow. It should always be kept very clean and free of faeces. There should be no loose troughs in the pen, particularly water troughs, as the pig may upset them immediately before farrowing and wet the litter. The pen should be equipped with farrowing rails (Fig. 14.8). These should be spaced at least 20 cm from the wall and 25 cm from the ground. They can be made from 5 cm diameter water pipe or from 8 cm2 hardwood timber. These farrowing rails provide an area within which the young piglet can be protected against its mother inadvertently lying upon it. Gilts are the least danger to their piglets, but as sows become older and heavier the possibility increases of them lying on and crushing their piglets.

Some farmers use a farrowing crate instead of rails. This is a crate in which the sow is confined at farrowing, the piglets being able to creep out of it. Farrowing crates should measure 2.22.4 m × 0.60.7 m with at least 20 cm floor clearance in order to allow the piglets to run around freely. The disadvantage of the farrowing crate is that the sow is very cramped and the use of these

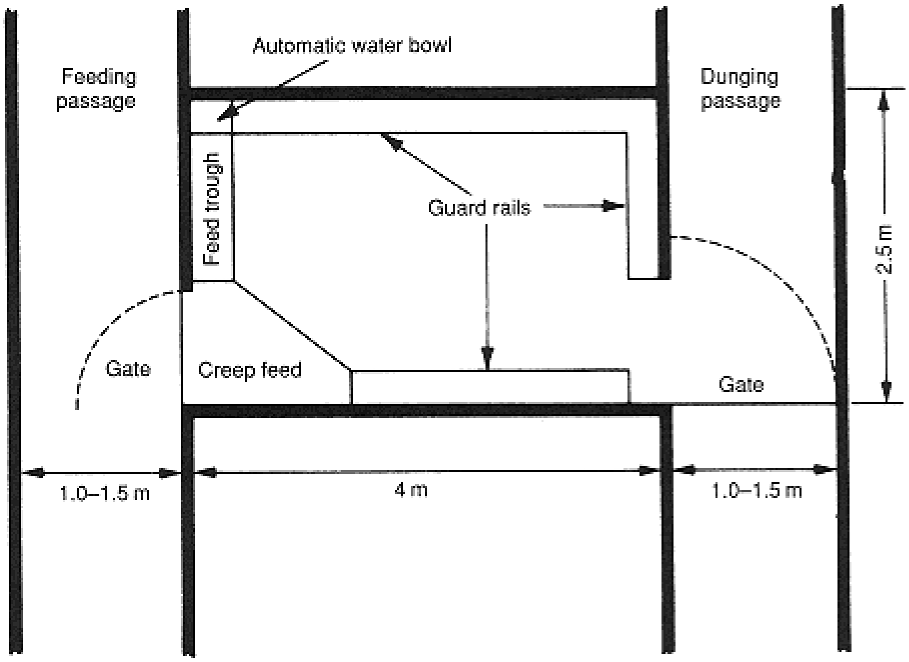

Fig. 14.8
A simple type of farrowing pen.

crates is not recommended. The sow is usually removed from the crate a few days after farrowing. If this is the practice then a pen with farrowing rails is still required.

A modification of the New Zealand type of farrowing pen known as the Ruakura round farrowing house (Fig. 14.9), suitable for use in the tropics, was devised by one of the authors. Practice in both Fiji and East Africa demonstrated that this is a very successful farrowing pen. In a trial using 36 litters, piglet mortality in an orthodox farrowing pen was 29% while it was 1.2% in the tropical-type round house.

Mature sows of good breeding that are well fed and managed usually farrow 814 piglets. Gilts normally farrow fewer.

Some 36 hours before gestation the vulva swells and the teats harden. Sows do not usually have any trouble in delivery. The newborn pig is small and may be delivered head or tail first. Piglets are usually born over a period lasting 112 hours. They are covered by a membrane that is ruptured at birth and thrown off by the piglet. Occasionally this membrane gets entangled over the snout and the piglet is suffocated. The first piglet will suckle before the last piglet is born. When all piglets are born the afterbirth is expelled and the gestating pig usually eats it. This is quite natural.

Generally farrowing should not be assisted, but it is wise to return from time to time to watch progress in order to be satisfied that all is proceeding smoothly. For example, the occasional piglet that does become entangled and is suffering in the fetal membrane may be saved. The navel cord of the newborn piglet should not normally be severed as it will shrivel up quite naturally. If it is severed it should be dipped in or dabbed with an iodine solution to prevent infection. This solution should consist of 2% iodine in 70% ethyl alcohol. The teeth of the piglets should not be cut unless the mother's teats become very sore.

Farrowing Troubles

The major troubles at farrowing are mastitis or inflammation of the udder caused by one or

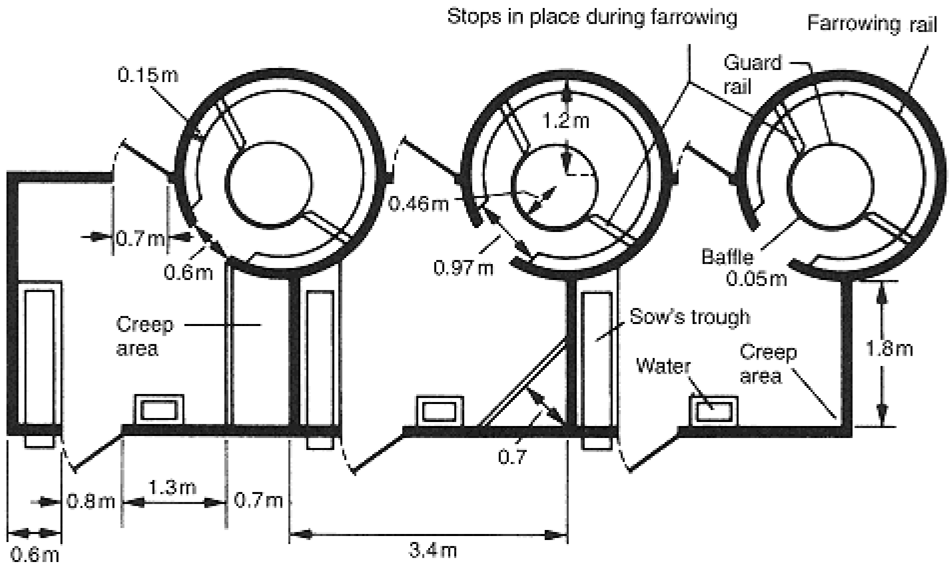

Fig. 14.9
Ground plan of a Ruakura round farrowing house.

more of a variety of microorganisms and agalactia or failure to secrete milk.

Specific 'lines' of pigs are more susceptible to mastitis than others and it may be found advisable to stop selecting breeding pigs from these lines. Mastitis can be treated using a variety of antibiotics, and veterinary advice should be sought as to the most effective mastitis-control programme.

The causes of agalactia are not always the same. Failure to secrete colostrum during the first 24 hours may simply be due to an insufficient internal secretion of the hormone known as oxytocin. This may be remedied by the intravenous injection of 510 IU of oxytocin. Later failure of milk secretion may be due to constipation which can be cured by the administration of a suitable laxative (e.g. castor oil), or to an inflammation of the vulva and/or udder that causes a fever and that may be due to a variety of causes including the retention of a fetus in the uterus. Under these circumstances professional veterinary advice should be sought.

The most serious effect of either mastitis or agalactia is that the piglets may have to be removed from the sow. They can then be either hand-reared or placed on a foster mother. The foster mother should farrow after the pigs are born so that they obtain some colostrum, and it is usually considered that there should be no more than 3 days' difference in age between the foster mother's own piglets and the orphan piglets that are given to her. Piglets can, with some difficulty, be successfully raised on diluted cows' milk together with a little antibiotic. They should be fed with a teat attached to a bottle until they learn to drink out of a shallow pan. This should be within 2448 hours from the time that they are taken from their mother. Great advances have been made in recent years in techniques for the artificial rearing of piglets and further information should be sought by the interested reader in relevant publications.

Piglet Mortality

Experimental evidence suggests that piglet mortality in the tropics is of the same order as piglet mortality in similarly managed herds in the temperate zone. Details of the cause of piglet mortality in an experimental herd in Fiji are shown in Table 14.10. The major mortality was caused by sows overlaying piglets. This is a loss that can be drastically reduced, as mentioned above, by the use of suitable farrowing equipment. As mortality due to overlaying is usually lower in first and second litters some farmers advocate the culling of sows after two litters. This is probably an uneconomic practice and it is more rational to spend capital on the provision of properly designed farrowing houses.

Suckling Piglets

Suckling and Creep Feeding

Piglets start suckling immediately after birth. The strongest piglets find the best teats and usually after a few hours of interchange each piglet keeps to its own teat. No attempt should be made to raise more piglets than the sow has teats, however many piglets are born. Surplus piglets may be raised by hand or on a foster mother. As stated in previous sections, breeding pigs should preferably always possess at least 1214 teats.

Solid 'creep' feeds should be introduced from 1 week of age. Creep feeding is the practice of feeding piglets separate from their mother. It is a desirable and economic practice as the nutritional needs of the young piglet are very different from those of the sow. Feeds suitable for the sow are too coarse and unpalatable for the piglets, and feeds suitable for the piglets are too expensive to feed to the sow. Creep feeds should be fed dry and piglets prefer them to be pelleted or crumbled. Water should always be available. Creep feeds can be fed in self-feeders or ordinary troughs. What is important is that the mother should not be able to eat the piglets' feed. A simple creep-feeding area can be made quite easily by barricading off the corner of a pen. After 3 weeks the piglets will be eating a considerable quantity of the creep feed.

The total quantity of the sow's ration should be raised gradually after farrowing and should be calculated according to the number of piglets that she is suckling. Details of feeding practices have been given in a previous section. The peak of milk production occurs about 3 weeks after farrowing, after which milk production slowly declines. The natural lactation length is approximately 12 weeks, but the normal practice is to wean at 8 weeks or earlier. Under good management pigs weaned at 8 weeks should weigh 1418 kg.

If the farmer wishes to wean at an earlier age then he should feed a creep ration with a higher nutritive value than the one normally used for piglets that are to be weaned at 8 weeks of age. Early weaning does appear to offer some advantages. These include the possibility of allowing the sow to farrow three times instead of twice a year or at least five times in 2 years. Also the possibility that piglets will grow faster, achieving a liveweight of 25 kg at 8 weeks. The sow should not lose too much weight. Feed costs should be less as there does not have to be such a long period during which there is a double conversion of foodfirst by the sow into milk and then by the piglet from milk into liveweight. Finally, as early weaned pigs require relatively high ambient temperatures (26°C at 16 days of age), supplementary heating of the piglet accommodation is not normally required in the tropics. It should be emphasized, however, that attempts at early weaning in the tropics have often been unsuccessful. In order to succeed both management and feeding have to be of the highest standard. To summarize, early weaning is not advised as a managerial practice for the average farmer in the tropics.

Piglet Anaemia

Piglets are born with a relatively small reserve of iron in their body and their mother's milk does not normally provide sufficient iron for their requirements. Consequently, piglet anaemia caused by an iron deficiency often occurs is piglets raised in the temperate zone although symptoms of this deficiency are not so frequently seen in piglets raised in the tropics. Anaemic piglets are pale in the regions of the ears and belly, are listless, breathe rapidly and often exhibit diarrhoea.

Piglet anaemia can be checked by:

(1) Placing fresh, clean earth in the piglet's pen each day.

(2) Using soil drenched with a solution made

from 500 g ferrosulphate, 75 g copper sulphate and 3 litres of water.

(3) The daily administration of 4 ml of a 1.8% ferrosulphate solution.

(4) The daily painting of the mother's udder with ferrosulphate solution and sugar.

All these methods are labour intensive and the safest and easiest method of combating piglet anaemia is to inject the piglet with a minimum of 100 mg of iron in the form of iron dextran 3 days after birth. If necessary, a second and slightly smaller injection can be made some 3 weeks later.

Marking and Castration.

Piglets should be ear-tattooed immediately after birth and the same animals ear-punched at 6 weeks of age (see Appendix I for further details). It is useless to ear-punch at too early an age as the punched ear of the very young pig grows together. A suitable ear-punching pattern is shown in Fig. 14.10. Ear tags are not usually successful when used on pigs although there is a type of press-stud ear tag that is said to work. The authors have not tried it.

Male piglets not required for breeding are generally castrated as this operation facilitates ease of management and prevents indiscriminate

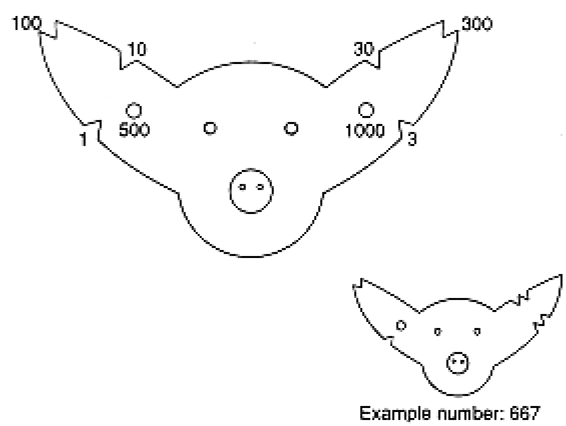

Fig. 14.10
A suitable ear-punching pattern for marking pigs.

mating. It does, however, slightly reduce the efficiency of food conversion in the animal. earlier castration is carried out, the easier the operation is to perform, and it is usually conducted 1 week or 10 days before weaning. This allows the piglet to recover from the castration check before it receives a weaning check.

Castration is best performed with a knife. The piglet can be held in one of two ways. It can either be set on a board or held up by its hind legs with its forelegs on the floor. Two people are needed, one to hold the pig and one to carry out the operation. First an antiseptic should be smeared over the scrotum. A testicle should be squeezed up in one hand while a cut is made with the knife held in the other. The cut should be made as far forward as possible in order to facilitate drainage. When the testicle is exposed it should be pulled out and the cord divided by scraping. The operation is then repeated on the other testicle. Illustrations of the operation are shown in Fig. 14.11.

If one testicle has not descended from the abdominal cavity, as sometimes occurs, the pig is known as a 'rig'. This is usually an inherited defect. Such pigs should never be retained for breeding purposes.

Weaning and Weaners

At weaning the sow should be taken away from the piglets and not the piglets from the sow. Weaning should be gradual and not an abrupt process. At first the sow should be taken away for a few hours, then for a whole day and finally for all time. The sow's ration should be reduced gradually during the weaning period.

Piglets should be drenched with a vermifuge such as piperazine immediately after weaning in order to control internal parasites. Occasionally a sow comes on heat while she is suckling, but this is unusual. If she does come on heat she should be served. Normally, she will come on heat 25 days after she has ceased lactating. If she is not served at this time she may be difficult to get in-pig. If the piglets are weaned early

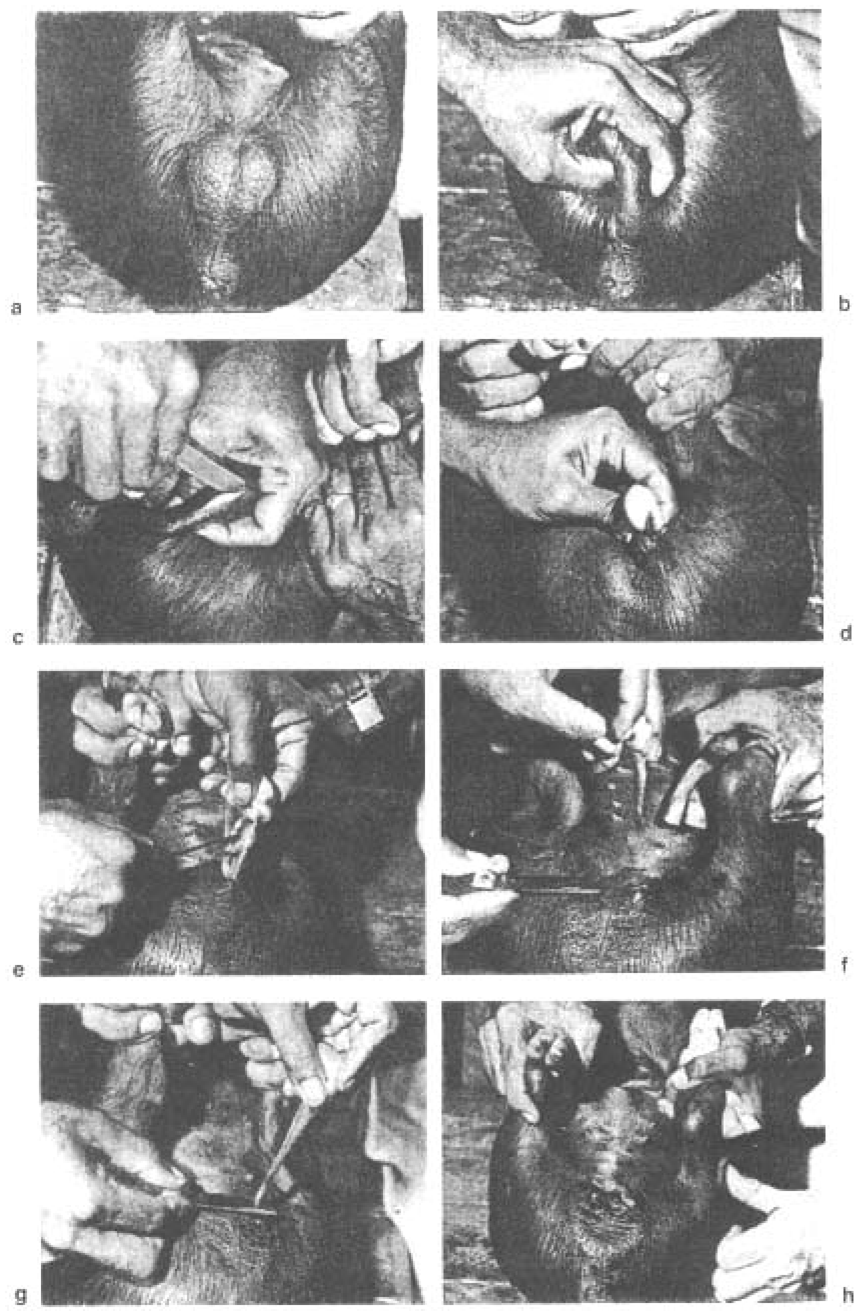

Fig. 14.11
Normal method of castrating a pig using a knife.

the sow should be served as soon as she comes on heat, which should be within a few days of weaning.

The average number of piglets born is probably a breed characteristic, but the average number weaned and the weight at weaning is mainly determined by the standard of management and feeding.

Fatteners

Few pigs are raised for bacon or for lard purposes in the tropics. Most are raised for pork and they are generally slaughtered at 4565 kg liveweight.

Pigs are usually fattened in groups of the same age. If litter mates can be fattened together, so much the better.

The efficiency of management and the suit-ability of the rations utilized can be checked by weighing the pigs regularly and comparing their liveweights with those shown in Table 14.8. In most regions in the tropics a porker weighing 55 kg should be produced in 5 months. Fattening rate does, however, depend upon inherited abilities as well as on feeding and managerial practices. In general, crossbred pigs should fatten more rapidly than purebred pigs. Hogs usually fatten faster than gilts of the same breed.

Meal for fatteners can be fed wet or dry. It is normally more practical to feed it dry. It is essential to feed it dry if self-feeders or automatic feeders are used. Pigs should be fed at regular intervals as they become restless if feeding times are irregular. They should also be fed to appetite but not to repletion, and a certain finesse has to be shown in management in order to accomplish this.

Growing pigs should be drenched with a vermifuge such as piperazine at 1516 weeks of age in order to ensure control of internal parasites.

Records

Breeding and liveweight records are essential for the commercial farmer. Other publications or extension officers should be consulted as to the most suitable form of records.

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15
Domesticated Birds

Introduction

As least 10 types of domesticated bird are of some importance in the tropics. These are the domestic fowl (*Gallus gallus*), the common duck (*Anas platyrhynchos*), the Muscovy duck (*Cairina moschata*), the goose (*Anser anser*), the turkey (*Meleagris gallopavo*), peafowl (*Pavo* spp.), Japanese quail (*Coturnix coturnix*), guinea fowl (*Numida* spp.), pigeons (*Columba livia*) and the ostrich (*Struthio* spp.). Megapodes are of regional importance in New Guinea and adjacent Pacific islands. Of the common species domestic fowls are by far the most important in the tropicsas indeed they are elsewhere. The main attention in this chapter will therefore be centred on the problems of domestic fowl production.

The outstanding feature of poultry production in tropical countries is the speed and extent of the changes that have taken place since the 1960s. When the first edition of this book was published in 1959 the authors could state quite categorically, 'that in few places is it [the poultry industry] a specialized industry and rarely does it form the sole means of livelihood or even a major source of income'. This is no longer true. Industrialized production methods, new breeds and improved health measures have been introduced from the temperate zone into almost all tropical countries with revolutionary effect.

Possibly the fastest growth in poultry production since the 1960s has been in Western Asia and North Africa, but there have been significant gains in the production and consumption of poultry products in countries throughout the tropics and subtropics. Although the world averages per capita per year for the consumption of eggs and poultry meat are 118 and 5.5 kg, respectively, these data conceal wide discrepancies between countries (Daghir, 1995c). An example would be the difference in annual per capita consumption between the United States and Egypt of 209 and 25 eggs and 32.0 and 1.2 kg poultry meat, respectively (Daghir, 1995c). These data suggest that the expansion of the industry in the tropics and subtropics could continue for a long time, but it must be emphasized that the new poultry industry is essentially an urban phenomenon, financed by urban capital, mainly benefiting urban-orientated producers and urban consumers and generally sited adjacent to the cities and larger towns. As a consequence the revolution in poultry production methods has hardly affected subsistence and semi-subsistence producers in the myriads of villages throughout the tropics. Countless millions of people still depend upon backyard or small-scale poultry production for supplies of eggs and poultry meat. In Southeast Asia, for example, 80% of the fowl population of the Philippines are still managed in backyards, whilst in Indonesia 90% of poultry meat is produced by scavenging flocks (Daghir 1995c).

The availability of capital and the increasing worldwide cost of energy, purchased feeds, equipment and pharmaceuticals, may in the long term, delay or even halt the complete industrialization and urbanization of poultry production in tropical countries. Under these circumstances subsistence and small-scale production methods may become relatively attractive to some sections of the population, particularly if minor but additive improvements in production methods can be introduced at the village level. This chapter has therefore been written to provide information primarily for extension officers and farmers concerned with subsistance and small-scale poultry production, but where appropriate, as with the effect of climate on poultry production, information is provided that should be of assistance to small and large producers.

Domestic Fowls

Origin and Domestication.

There are four wild species from which domestic fowls could have originated: the red jungle fowl (*Gallus gallus*), of which five subspecies are recognized, distributed from northwest India and south China to the Pacific islands; the green or Javanese jungle fowl (*G. varius*) found in Java and Indonesian islands to the east; *G. sonnerati*, the grey jungle fowl indigenous to southern India; and *G. lafayetti*, the Lafayette or Singalese jungle fowl, found only in Sri Lanka. All four species hybridize with domestic fowls, though only *G. gallus* crossbreds are fully fertile. Some authorities consider that *G. gallus* is the only ancestor of the domestic fowl and designate the latter as *G. gallus* with the chromosome number (n = 78). Others believe that all four wild species have contributed genes to the domestic fowl, though *G. gallus* may have been the major contributor, and designate the domestic fowl as *G. domesticus* (Crawford, 1984a).

The centre of domestication is unknown. The subject was considered in some detail by Crawford (1984a). In view of the very wide distribution of the wild species, in South Asia and throughout mainland Southeast Asia to the off-shore islands of Indonesia, it is possible that there were several centres of domestication. Today in Southeast Asia the distribution of the red jungle fowl is closely associated with the occurrence of shifting agriculture (Callias & Saichuae, 1967). These authors suggest that under such circumstances domestication could easily have been initiated and they cite examples of the present-day domestication of wild birds. Certainly, as stated above, wild fowls will interbreed with domestic fowls. An interesting example is found on the island of Madura in Indonesia, where wild cocks are captured, tamed and mated with village hens to produce *begisar* or 'song cockerels'.

Zeuner (1963) stated that domesticated fowls could certainly be found in the Indus valley by 4000 BP (before present), that they were reared in what is now Iran by 2800 BP and that the Persians probably spread them throughout Western Asia and to the shores of the Mediterranean by 2600 BP. They were common in Italy by 2400 BP and were introduced into northern Europe by 2100 BP. Fowls were used for different purposes in different cultures. They were probably first used for cockfighting (Crawford, 1984a), then they assumed a religious significance, being used for sacrificial and soothsaying purposes, finally becoming of economic significance first as egg and then as meat producers.

It is possible that fowls had become of economic importance by 2000 BP in some, but not all regions of Europe. They were of economic importance in China somewhat earlier, *c*. 3500 BP. Fowls were introduced into the northern Philippine islands from China *c*. 2000 BP, but it is possible that other types had been introduced at an earlier date from Indonesia.

Early European explorers in the Pacific noted that fowls were present on virtually all Pacific islands. It was considered that the birds had been introduced from Southeast Asia, first by the Melanesians and then by the Polynesians, some 3000 years ago. Recent archaeological discoveries in Fiji, however, suggest that colonization of many Pacific islands occurred at an earlier date, so that fowls introduced from Southeast Asia may have been present in some Pacific islands for much longer than 3000 years.

The first introduction of fowls to Africa was probably from Western Asia to Egypt *c*. 3500 BP (Zeuner, 1963). Later there appear to have been introductions of fowls from India to East Africa, from where some were apparently introduced to

West Africa, as words for the domestic fowl in some East and West African languages possess an Indian *root* (Carter, 1971).

It is generally agreed that domestic fowls were introduced into the Americas by Europeans in the fifteenth and sixteenth centuries, but Carter (1971) has assembled biological, cultural and linguistic data that suggest that fowls were introduced to the Americas from the Pacific region before the European conquest. There is, however, no conclusive evidence for this theory.

The available evidence suggests that domestic fowls were present, not only in South Asia and Southeast Asia but also in Eastern and Western Asia, many Pacific islands and Northeast Africa, before they were introduced into Europe. Nevertheless, major advances in the breeding of domestic fowls have taken place in Europe and in the Americas.

Number and Distribution

Some details of the world distribution of domestic fowls are provided in Table 15.1. It is likely, for a variety of reasons, that total numbers are grossly underestimated by the FAO, but the table probably provides a guide to the relative distribution of domestic fowls in the tropics.

About one-third of the world's domestic fowl population are to be found in tropical regions and of the total number in the tropics somewhat less than half are reared in tropical Asia. The total number of domestic fowls is increasing in all continents but the percentage reared in the tropical regions of those continents is not; at 32% it was approximately the same in 1994 as it had been in 197476. Nevertheless, there were differences in the growth rates of the fowl population between tropical regions, with the fastest growth rate in Asia (Table 15.1).

Table 15.1 Number and distribution of domestic fowl. (*Sources*: FAO, 1983, 1995.)

Continent/region	No. domestic fowl (million) 197476	1994	No. in 1994 as % no. in 197476	Total in continent/region as % world total
Africa	472	976	207	8.4
Tropics	367	671	183	5.8
Other	105	305	290	2.6
Americas	1183	3252	275	28.0
Tropics	580	1352	233	11.6
Other	603	1900	315	16.4
Asia	1760	5553	316	47.8
Tropics	523	1724	330	14.8
Other	1237	3829	310	33.0
*Europe*a	1134	1754	155	15.1
Oceania	53	85	160	0.7
Tropics	12	23	192	0.2
Other	41	62	151	0.5
World				
Tropics	1482	3770	254	
Other	3120	7850	252	

a Any comparison of the number of fowls in Europe cannot be very accurate as the European regions of the former USSR are included in the 1994 but not in the 197476 data.

Breeds

The majority of breeds used today by commercial poultry-keepers are hybrids that have been bred by the large-scale international poultry-breeding corporations, and fertile eggs, day-old chicks or parental breeding stock are imported into tropical countries, primarily from temperate climates. Under good management the productivity of these hybrids can be very high. Fowls lay 250270 white shelled eggs per annum, weighing 62 g on average. Body size in 1.25 kg at sexual maturity and 1.7 kg at conformation maturity. Male broilers weigh 1.9 kg at 44 days with a feed conversion of 1.9:1.0. Females show a somewhat lower productivity. Those interested in purchasing hybrid breeding stock should consult their extension organization or representatives of the international corporations who are established in many tropical countries.

If for some reason hybrid breeding stock are not available from the international corporations then the improved pure breeds most commonly used are of three types: those developed for high egg production, those bred specifically for meat production, and dual-purpose breeds.

The breeds used for high egg production are mainly of Mediterranean origin and the most popular are the *Leghorn*, *Ancona* and *Minorcan*. The *White Leghorn* is the most widely used white egg producing breed. Mature cockerels and hens weigh approximately 2.7 kg and 1.8 kg, respectively. The hens do not go broody very easily so that it is necessary to set the eggs under a hen of another breed or to incubate them artificially. Hens are very good layers with a high efficiency of feed conversion, but birds of this breed do not produce good carcases. They appear to be more heat tolerant than other commercial breeds, although in other ways they are not particularly hardy.

Meat-producing types are typified by the *Orpington, Cornish* and *Jersey Black Giant*. These are heavy breeds, mature cockerels of the three breeds weighing 3.9 kg, 3.9 kg and 5.0 kg, respectively. These breeds are not normally economical egg producers or particularly heat tolerant. Apart from the White Leghorn, dual-purpose, brown egg producing breeds such as the *Rhode Island Red* (RIR), *New Hampshire* and *Australorp* are the most popular breeds used in tropical countries. Mature RIR cockerels and hens weigh approximately 3.6 kg and 2.7 kg respectively. The RIR hens are good layers and meat producers, but they possess a yellow-skinned carcase, unliked by some consumers. They go broody very easily, but thrive well in the humid tropics. The New Hampshire is an early maturing breed. Mature cockerels and hens weigh 4 kg and 2.6 kg, respectively. Australorps have been extensively used in Southeast Asia, although hens of this breed do not lay as well as some of the other breeds mentioned and quickly go broody. The breed crosses well with the White Leghorn. Mature cockerels and hens weigh 3.6 kg and 2.7 kg, respectively.

In some countries the government imports selected pure lines of poultry and breeds from them large numbers of exotic purebreds or crossbreds for use in village upgrading programmes or by commercial producers. The Government Poultry Breeding Programme in India is an example of such a scheme.

Where fowls have to hatch their own brood, scavenge for the major part of their food and are unprotected against predators and endemic disease, then indigenous breeds should be used. There are innumerable types. A catalogue of those in Southeast Asia has been published (Bay-Petersen, 1991).

In those countries where the main functions of domestic fowl in the past were to supply meat and provide fighting cocks, body-size and vigour have been the traits for which they have been selected. There are many such breeds; the Indian *Aseel* being a typical example. These fowl grow very slowly. Even under the best of managerial conditions they only achieve a liveweight of approximately 1.8 kg in 6 months, but cockerels and hens grow on to achieve mature liveweights of 4.5 kg and 3.23.6 kg, respectively. The breast and thighs of the cockerels are particularly well developed and the pullets are also valuable meat producers. The average egg production of this breed is 35 per annum.

Some indigenous breeds produce a relatively large number of eggs in a year, but the eggs are invariably small compared with those of exotic breeds. The *White Chittagong* of India is an example. The hens lay on average 130 small eggs per annum. The *Canton* of Malaysia is a similar breed. Under good managerial conditions hens of this breed will produce 120 eggs per annum with an average weight of 42 g, although under village conditions the average egg production is probably no more than 80 per annum.

In general, the average indigenous fowl in the tropics probably weighs 0.91.8 kg and possesses a somewhat light covering of wiry feathers that are free from down. A naked neck is a feature of some breeds, while others possess naked or nearly naked thighs. These are characteristics that may improve heat tolerance. The feather colouring is very varied, but most often it is a lighter or darker shade of brown intermingled with red or gold. A black colour is fairly common, as is 'barring'. A white colour is unusual. In cockerels male characteristics are marked. Females normally possess small heads and usually lay up to three clutches of 1218 eggs each year. The weight of an average egg is about 28 g. Broodiness is pronounced. All these fowls are normally active and vigorous foragers, well adapted to tropical environments. In India, the productivity of the *Kadaknath*, or indigenous fowl, has been improved without sacrificing some of the characteristics required by village fowls (Panda, 1987).

Often exotic purebred fowls have been used to upgrade indigenous village flocks. Experience has shown that such upgrading is not likely to be very successful unless there is at the same time a parallel improvement in management and feeding. It has also been shown to be a mistake to introduce a small number of exotic cockerels into a village flock. They are invariably intimidated and/or killed by the more vigorous indigenous cockerels. If upgrading of village flocks is to be practised, then all the indigenous cockerels should be replaced by exotic cockerels at the same time. In India the use of exotic White Leghorn × Australorp or White Leghorn × RIR hybrid cocks for village flock upgrading has had some success, advantage being taken of the hybrid vigour of the crossbred cockerels and their superior viability to purebred exotic cockerels in the village environment.

The present situation in most tropical countries is that the international corporations are providing hybrid stock for the majority of commercial operators, a few producers are still using the improved breeds that have been used as parental stock by the international corporations and there are unimproved, indigenous breeds in the villages. This is a dangerous situation. As the poultry industry develops, improved and indigenous breeds could disappear. International, government and private organizations need to act rapidly to preserve valuable genetic stocks.

Effect of Climate

The physiological response of fowls to an increase in the ambient temperature above 30°C is for feed intake to fall and water consumption to increase. In the longer term liveweight gain is reduced, eggs are smaller and reproductive vigour declines. At ambient temperatures above 32°C with 5060% humidity alkalosis may occur. This can reduce eggshell calcification, producing thin-shelled eggs, and affect bone formation, causing leg problems in growing birds (Etches *et al*., 1995).

Methods of heat disposal for fowls can be behavioural and/or physiological. As the ambient temperature rises fowls move less, attempt to distance themselves from each other and allow their wings to droop and be lifted slightly away from their body. If water is freely available they will splash it on their combs and wattles.

Compared with some mammals the physiological methods by which fowls can dispose of heat are limited. The major method is panting. This facilitates evaporative heat loss from the mouth and the respiratory passageways that is at a maximum when the ambient temperature is 32°C and the relative humidity 5060%. Fowls can also dispose of some heat by radiation and conduction. The blood flow to combs, wattles and shanks can be radically increased and at high ambient temperatures the cooler venous blood can be brought into close proximity with the warm arterial blood in the vascular system of the legs and feet, providing a quite efficient form of heat exchanger (Etches *et al*., 1995). These physiological responses are controlled by complex hormone interactions that are not yet fully explored.

In practice, ambient temperatures in the tropics are not usually above 30°C throughout the year or even in some seasons throughout the 24 hours. Nevertheless, every effort must be made to protect fowls from excessive heat and humidity.

Egg production can be efficient at an ambient temperature of 32°C but not at higher temperatures (Marsden & Morris, 1981). The birds must be acclimatized, provided with adequate supplies of water, receive a suitable diet and be properly housed and managed. In practice laying birds would normally be managed at a slightly lower average temperature than 32°C. Payne (1967) has shown that considerable savings in feed costs can be achieved by maintaining laying-house temperatures at 2930°C.

At ambient temperatures above 32°C egg production and egg size decrease and egg shells may become thinner (Smith, 1974). Small egg size is a characteristic of indigenous tropical fowl breeds, so that this trait may simply be one of the adaptations that have to be made by fowls in a tropical climate.

In the case of broilers experimental data suggest that those reared at ambient temperatures within the range 219°C are somewhat heavier than similar stock reared within the ambient temperature range of 1935°C, but that their efficiency of food conversion is less. Thus the tropics, where mean annual ambient temperatures are of the order of 2728°C, would appear to be a very suitable region in which to rear broilers if cheap feedstuffs and good management and services are available. Present data suggest that the drier tropics may be a superior environment to the humid tropics for broiler production.

With regard to the choice of breed for tropical climates, White Leghorns appear to be more heat tolerant (HT) than most other internationally used breeds (Emmans & Charles, 1977), but many indigenous tropical breeds are certainly as tolerant if not more tolerant than White Leghorn and there are strain differences with regard to HT in all breeds. It is also feasible to select for HT in fowls as the heritability of the characteristics that determine HT is quite high (Gowe & Fairfull, 1995). An alternative policy would be to introduce genes that improve HT into existing, productive breeds.

There are several inherited characteristics in fowls that could improve HT. The more important are 'naked neck', 'frizzle' and 'dwarfing'. When homogenous, the characteristic 'naked neck' reduces feathering by 40% and when heterozygous by 30%. This improves the HT of the bird. Naked neck birds have a high viability and superior feed efficiency managed at ambient temperatures above 30°C but the eggs have a lower hatchability. The 'frizzle' characteristic (Fig. 15.1) is useful in humid climates, whilst in the 'dwarfing' type liveweight is lowered by 2632%, reducing space requirements for breeders, whilst feed efficiency is high (Gowe & Fairfull, 1995). The possibility of incorporating one or other of these characteristics that improve HT in

Fig. 15.1
The 'naked neck and frizzle' characteristics in a Peruvian fowl.

economically viable breeds is being explored at the present time.

Feeding

Very considerable advances have been made in poultry nutrition since the first edition of this book was published. For example, it is estimated that in 1966 a male broiler required 5.1 kg of feed and 74 days to achieve a liveweight of 2 kg, whereas in the 1980s 3.6 kg of feed and a period of 44 days were required. In addition, in some tropical countries a poultry-feed industry has developed and commercial poultry rations are sometimes available that have been formulated using least-cost methods based on linear programming. These rations are available not only to the commercial producer but also, in many tropical countries, to the small farmer and backyard poultry-keeper.

The authors therefore intend to indicate only briefly some recent advances in poultry nutrition, to discuss the special requirements of poultry in a tropical climate, to advise as to the publications in which details of poultry nutritive requirements can be readily found, and to provide some general information for those small and backyard poultry-keepers who cannot afford, or do not have access to, commercial poultry rations.

In a general way poultry nutritionists are now concerned to formulate rations that do not necessarily ensure maximum production but the most economic performance. It is obvious, therefore, that information is required on the range of energy levels that can be tolerated in rations for different classes of poultry. Also very complete information is required on the amino acid, mineral and vitamin contents of available feeds. Even though energy levels alter, a constant energy/protein ratio is required and as the protein level changes it is important that the relative amounts of amino acids should remain constant. Overall, one of the major aims of poultry nutritionists is to provide specific inputs of required nutrients per unit of liveweight for the different classes of poultry. For example, it is now suggested that in broiler production males and females should be fed separately as female broilers grow at a slower rate and require slightly more feed than males.

Considerable attention has been paid to the effect of processing on the nutritive value and palatability of feeds, and major improvements in processing methods have been made. The possibility of restricting energy intake to levels below those that are normal, where there is a free choice of feed, are under investigation. If energy intake is restricted it is of course necessary to increase the amino acid, vitamin and mineral contents of the feed. The use of individual synthetic amino acids to fortify feeds deficient in a specific amino acid is now generally practised and the uses of new sources of protein, in particular single-cell yeast, algae and bacterial protein, are being actively investigated. There is information on the mineral requirements of poultry that suggests that nickel, tin, vanadium, silicon and fluorine are all essential mineral nutrients, that selenium may be an essential mineral nutrient independent of its interactions with vitamin E and that the requirements of poultry for zinc and iron are rather higher than had been recommended in the past (Taylor, 1975).

Feed Requirements

Estimates of the nutrient requirements of poultry in the temperate zone have been published in the United States by the National Research Council (1994) and in the United Kingdom by the Agricultural Research Council (1975). A useful summary of feeding standards for poultry based on the above and other sources of information has been published by McDonald *et al*., (1981) and this is shown in Table 15.2. Some normal rates of inclusion of feeds available in the temperate zone have been published by Bolton & Blair (1977).

A major difficulty experienced in the tropics, both by the commercial formulators and small farmers who wishor are forced by circumstancesto mix their own rations, is that data on the average nutrient content of many local feeds are not available, or are based on data acquired

Table 15.2 Feeding standards for fowls. (*Source*: McDonald *et al*., 1981.)

Component	Growing chicks 06 weeks	612 weeks	Pullets 1218 weeks	Laying hens	Breeding hens	Broilers Starting	Finishing
ME (MJ/kg)	11.5	10.9	10.9	11.1	11.1	12.6	12.6
CP (g/kg)	210	145	120	160	160	230	190
Amino acids (g/kg)							
Arginine	11.0	7.1	6.7	4.9	4.9	12.6	9.5
Glycine + serine	13.2	9.4	8.0			12.0	11.0
Histidine	5.1	3.3	2.4	1.6	1.6	5.0	5.0
Isoleucine	9.0	5.9	4.5	5.3	5.3	9.0	8.0
Leucine	14.7	9.9	8.4	6.6	6.6	16.0	13.0
Lysine	11.0	7.4	6.6	7.3	7.3	12.5	10.0
Methionine + cystine	9.2	6.2	4.5	5.5	4.6	9.2	8.0
Phenylalanine + tyrosine	15.8	10.8	8.0	7.0	7.0	15.8	14.0
Threonine	7.4	4.9	4.2	3.5	3.5	8.0	6.5
Tryptophan	2.0	1.4	1.2	1.4	1.4	2.3	1.9
Valine	10.4	6.6	5.3	5.3	5.3	10.0	9.0
Major minerals (g/kg)							
Calcium	12.0	10.0	8.0	35.0	33.0	12.0	10.0
Phosphorus	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Magnesiuma	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sodium	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Potassium	3.0					3.0	3.0
Trace minerals (mg/kg)							
Coppera	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Iodinea	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Irona	80.0	80.0	80.0	80.0	80.0	80.0	45.0
Manganesea	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Zinca	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Selenium	0.15					0.15	0.15
Vitamins (IU/kg)							
Aa	2000	2000	2000	6000	6000	2000	2000

Da	600	600	600	800	800	600	600
Ea	25	25	25	25	25	25	25
Vitamins (mg/kg)							
Ka	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Thiamin	3.0				2.0	3.0	
Riboflavina	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Nicotinic acida	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Pantothenic acida	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Choline	1300				1100	1300	1300
Vitamin B12					0.01		

a Added as a supplement.
ME = metabolizable energy; CP = crude protein.

in other countries or in another region of the same country. This situation can only change as analytical facilities become more widespread and available. In the interim period a wide margin of safety must be accepted in order to ensure that the feed used in the ration does contain the required level of nutrients, despite regional differences in the nutrient content of the same feed, storage losses, etc.

Special Food Requirements in a Tropical Climate

Experimental work has shown that the level of energy consumption may be a major factor affecting egg production in tropical countries. Hens in a temperate zone with a mature weight of 1.8 kg receiving *ad libitum* rations containing 11.011.5 MJ/kg of metabolizable energy (ME) will consume approximately 1.31.4 MJ of ME daily when producing the maximum number of eggs. As previously stated, feed consumption falls with rising ambient temperature and a decrease in feed consumption of 1015% is not uncommon in the tropics. This means that the daily intake of ME may be only 1.11.2 MJ and this level of intake is insufficient for maximum egg-laying performance. Thus, every method of increasing feed consumption should be used. These could include encouraging feed intake in the early morning and in the evening when ambient temperatures are lower than they are during the remainder of the day; feeding high-energy diets; stirring the feed frequently; using pelleted feed; and providing ample supplies of cool, fresh water.

Laying hens normally exhibit two peak feed consumption periodsone at the time of lay and the other late in the afternoon. As hens begin to lay about 1 hour after first light, and light encourages feeding, the provision of additional light in the morning and again in the evening should encourage hens to eat during the cooler periods.

High-energy-content diets (12.012.5 MJ/kg) can be formulated and should be used. Fat can be used to formulate high energy diets and its addition stimulates feed and ME consumption at high ambient temperatures in growing stock, layers and broilers (Daghir, 1995b). Stirring the feed once or twice daily increases consumption but is a labour-intensive practice. Pelleting the feed also increases consumption, but this practice does have the disadvantage that it often encourages cannibalism. If may also increase water consumption. This of course is desirable. In any case ample fresh, clean water must be available as hens in the tropics will consume on average 500 ml of water per day compared with 200250 ml by hens in the temperate zone. Deprivation of water for only a few hours may affect egg production for several days. High-fibre-content rations will also decrease feed intake and hence egg production.

If feed consumption decreases during hot weather then as most poultry rations are formulated with a constant ME:CP ratio the crude protein (CP) content of the ration must be increased to ensure maximum egg production. In a ration containing 11.0 MJ ME/kg with a 16% CP content, the concentration of the latter should be raised to 1718%. On the other hand, if despite efforts to increase ME consumption egg production falls below 65%, i.e. an egg is laid on 65% of the possible days, then there is no necessity to increase the CP of the ration. Attention to the amino acid balance in the diet proteins is also important as avoiding excess of amino acids and improving amino acid balance help to minimize heat production.

More calcium must also be fed during hot weather to prevent an increase in the number of broken and cracked eggs produced. Additional calcium added to the ration will probably make it less palatable and tend to encourage a further decrease in total intake so that the calcium should be supplied partly in the ration and partly in the form of oyster-shell or limestone chips.

If feed intake decreases it will also be necessary to increase the concentrations of all the other minerals and vitamins in the ration. There is some evidence of improved performance at high ambient temperature when additional vitamins A and C are fed (Daghir, 1995b).

Feeding:
The Small Poultry-Keeper

There is ample evidence that if the feeding of indigenous poultry is improved they will become more productive. Improved feeding is even more important, indeed essential, if indigenous breeds are upgraded using exotic and more productive breeds.

Feeding may be improved in two ways. The birds may still be allowed to scavenge around the house compound but in addition be fed a daily basic ration, or they may be enclosed and fed complete rations. Up-graded birds may lose their scavenging abilities and it may be essential to feed them complete rations in an enclosure.

It is reasonable to suppose that scavenging poultry are usually able to secure adequate quantities of minerals and vitamins and some of their protein requirements but that they are not normally able to obtain an adequate supply of energy feeds. Thus, a ration for scavenging poultry should be energy-rich and contain moderate quantities of protein. Cereal grains are obviously suitable if they are available.

As it is unlikely that the small poultry-keeper or even all his extension advisers will have access to all the data provided in Table 15.2, it may be necessary to use a less sophisticated method of formulating poultry rations. Information on the CP content and perhaps part of the mineral content of local feeds may be available from proximate analyses, so that using the data in Table 15.2 for what information is available, rations can still be formulated. It is suggested that as many feeds as possible of those locally available should be used in making up the rations. This is particularly important as far as the protein-rich feeds are concerned, as a mixture should ensure that there is a reasonable chance of the ration providing all the essential amino acids required by the birds. In addition, a mineral mixture, green feed and an adequate supply of fresh, clean water should always be available in the pen. Examples of suitable rations formulated by Smetana (1966) in Burma (now Myanmar), where the animal-feed industry was not very sophisticated, are provided in Table 15.3.

Methods

Poultry that are not on range or scavenging should always be fed some hard grit as this is essential for the proper working of their digestive system. Hard metal screenings (3 mm), quartz and/or granite chips or coarse sand are all satisfactory. Grit should be fed in separate containers from at least 3 weeks of age.

When household scraps are fed care must be taken to see that they contain no toxic materials. Very salty feeds can be toxic, as can some mouldy feeds. Water must always be available and is best provided from automatic fountains. Simple automatic fountains can be easily made. The daily provision of some fresh green feed is desirable.

The feeds used in the formulation of a ration must of course be palatable. Mashes that are too light and dusty or too wet and sticky clog the nostrils and/or the beak and sooner or later cause aversion. Similarly, foods which distend the crop by swelling or which clog the gizzard because of their fibrous nature become unacceptable.

The main ways in which feeds are prepared and offered to poultry are as follows:

(1) *Dry mash*. In addition grit and green feed are fed. There is often some wastage at the troughs.

(2) *Dry mash and grain*. The dry mash should always be available and the grain fed in separate troughs once a day. The CP, mineral and vitamin contents of dry mash fed with grain should be superior to that of dry mash fed alone.

(3) *Wet mash*. There are no particular advantages in feeding wet mash and labour costs are increased.

(4) *Pellets or crumbles*. The feeding of these is to some extent advantageous. There is less wastage compared with the feeding of dry mash. Birds cannot select out specific feeds and are therefore likely to obtain all the nutrients included in the ration. However, the feeding of pellets does tend to increase the incidence of cannibalism.

Table 15.3 Examples of poultry rations formulated in Myanmar (Burma). (*Source*: Smetana, 1966.)

Feed	Chick starter ration[a] (%)	Chick grower ration[b] (%)	Meat cockerel finishing ration[c] (%)	Layer rations 1 (%)	Layer rations 2 (%)
Maize	25	15	30	25	
Broken rice	25	30	25	25	46
Rice bran	10	20		10	12
Groundnut meal	15	15	18	14	16
Sesame meal	10	10	10	10	10
Prawn meal[d]	15	7	14	10	10
Bone-meal (sterilized)		2	2	3	3
Oyster flour				3	3
Vitamin mix	+	1	1		
Green feed	+[e]				
Coccidiostat	+				
Calculated analysis					
Crude protein (%)	18.0	16.3	18.5	16.7	16.6
Calcium (%)	1.45	1.29	1.21	2.58	2.59
Phosphorus (%)	0.42	0.61	0.55	0.61	0.62

a Fed from day-old to 8 weeks of age.
b Fed from 8 weeks until maturity at 20 weeks.
c Fed to cockerels after they have been separated from the females at approximately 8 weeks of age.
d 33% crude protein content.
e It would be desirable to provide green feed to all stock and not just to the chicks.

Space.

Adequate feed space is very important. The feed trough should be accessible from all sides. As a general guide to the provision of feeding space, approximately half the total number of birds should be able to eat at any one time. Details of feed and water-trough requirements are given in Tables 15.4 and 15.5.

Consumption

It is important to be able to estimate average feed consumption in order to be able to budget for and purchase feeds. Monitoring of feed consumption by the poultry-keeper can also indicate changes in the health and productivity of the flock. Some information on the average consumption of food by different classes of birds is given in Table 15.6. This information should only be used as a very approximate guide as feed consumption obviously depends on many and varying factors.

Health

Poultry that have been well fed and managed and vaccinated against known local diseases usually remain healthy. The greatest emphasis should be on disease prevention, but if there is a disease outbreak, sick birds should be separated from healthy birds, strict sanitary measures should be applied in all housing and a veterinarian and/or extension worker should be immediately notified.

In order to assist readers in the recognition of major fowl diseases, some of the more important

Table 15.4 Feed trough requirements for different classes of poultry.

Type	Age (weeks)	Length of feed trough per 100 birdsa (m)	No. required and weight of feed in hanging feeders per 100 birdsb (kg)
Ducks	13	7.3	
	Mature	12.0	
Fowls			
Chicks raised for egg production	13	2.4	
	46	3.7	2 × 11.3
	712	4.8	
	1318	5.2	4 × 11.3
	Layers	7.610.7	6 × 11.3
Broiler chicks	13	2.7	
	46	75.2	
	712	7.6	6 × 11.3
Turkeys	14	5.27.6	
	58	9.112.2	
	816	12.215.2	
	Breeders	12.215.2	

a These requirements are based on the assumption that the feed troughs are accessible from both sides. If this is not the case the length should be doubled.
b For mature birds the hanging troughs should be 0.3 m above the ground.

Table 15.5 Water trough requirements for different classes of poultry in the tropics.

Type	Age (weeks)	Length of water trough per 100 birds (m)	No. water fountains and capacity (litres)
Fowls	14	1.0	
	58	1.82.0	4 × 2.3
	918	2.5	
	Laying	2.5	
Turkeys	14	1.01.3	
	58	2.5	
	916	3.0	
	Breeders	3.03.8	

The allowances are generous by temperate-zone standards, as under normal tropical conditions birds drink more frequently than they would in the temperate zone.

are listed in Table 15.7. Some other causes of ill-health are discussed below. For further details readers should consult a tropical veterinary textbook, such as Hall (1985).

Intestinal Parasites

Infestation usually occurs when birds are kept for too long a period on the same ground or

Table 15.6 Approximate food consumption of fowls at different ages.

Age of bird (weeks)	Approximate food consumption (kg)	
	Per week	Progressive total
18	0.140.50	2.4
920	0.540.90	10.5
Mature (laying bird)	0.90	

The estimates are for medium-sized breeds. Lighter and heavier breeds will have correspondingly smaller and larger consumptions.

when wet patches are allowed to develop in deep-litter houses. It is almost inevitable under backyard scavenging, managerial conditions.

• *Symptoms*. The birds lose condition, the feathers, combs and wattles may become dull and growth or egg production decrease. There is often diarrhoea and worms may be seen in the droppings. Heavy infestation may lead to the death of birds.

• *Treatment*. Birds should be dewormed using the appropriate drug. It is always advisable to seek the advice of a veterinarian and to have the worm(s) typed so that the most suitable and economic vermifuge can be utilized.

• *Prevention*. Good hygiene and feeding and the separate rearing of various age groups will go far to help reduce intestinal parasitism.

External Parasites

Lice are probably the most common poultry pest and they are often the cause of low egg production. They are easy to detect. If the birds are handled the lice will be seen moving about the base of the fluffy feathers found around the vent. An approved and effective insecticide should be used immediately and again 10 days later when the eggs of the lice, already attached to the birds, hatch. A light application of nicotine sulphate on the bird's hocks, just before roosting time, is a simple method of control. Perches and other wooden structures must also be dealt with and may be painted with crude oil, but this material should not be applied to nesting boxes as it may cause some contamination of the eggs.

Red mites are more difficult to recognize as they do not live on the birds, but only feed on them at night. Mild infestations can be dealt with in the same manner as lice infestations, but if the infestation is very severe the houseas long as it is of simple design and cheaply constructedmay have to be burnt.

Scaly leg mites are also difficult to eradicate. The legs of all infected birds should be repeatedly dipped in kerosene, the house thoroughly cleaned and any litter removed and burnt.

Vitamin and Mineral Deficiencies

Vitamin and mineral deficiencies in the rations can cause a variety of deficiency diseases in poultry. Properly formulated commercial rations should contain adequate amounts of all the essential vitamins and minerals, but farm mixed rations may sometimes be deficient in one or another. One insurance is to provide daily, adequate quantities of green feed in the pens.

Mycotoxins

The term mycotoxin is used to describe all toxins derived from fungi that cause ill-health in domestic birds and other species. Mycotoxin contamination of feedstuffs was first recognized in the United Kingdom in the 1960s with the discovery of aflatoxin in imported peanut meal that had caused disease in young turkeys.

Tropical and subtropical environments, particularly those that are humid, favour the production of mycotoxins from fungi developing on harvested crops. Aflatoxin is the common name for a group of toxins produced by fungi of the genus *Aspergillus*. Numbers of other important mycotoxins have been recognized but aflatoxin is the one that has been studied most intensively.

Fowls are not as susceptible to aflatoxin as ducks and some other birds, but at concentrations below 2.5 ppm the toxin affects growth in broilers and at even lower concentrations it decreases egg production and egg weight in

Table 15.7 Some of the more important diseases of fowls.

Disease	Cause (organism)	Symptoms	Treatment	Prevention
Bacterial				
Bacillary white diarrhoea (BWD) or pullorum disease	*Salmonella pullorum*	White diarrhoea; refusal to eat; huddle with wings hanging down	Furazolidone at 0.4% mash daily for 10 days	Transmitted via eggs so ensure breeding stock are free; rigorous sanitation. Annual testing.
Fowl typhoid Kikuyu fowl disease in East Africa	*Salmonella gallinarum*	Green diarrhoea; otherwise similar to BWD	As for BWD	Vaccination at 8 weeks. Regular agglutination tests for carriers.
Avian paratyphoid Salmonellosis	*Salmonella* spp. other than those causing BWD and typhoid	Similar to BWD	As for BWD	Fumigation. Elimination of vermin.
Fowl cholera	*Pasteurella multocida*	Laboured breathing; dark droppings; high temperature; very red comb that may turn almost black	Sulphonamides may be used	Good management and sanitation combined with vaccination.
Viral				
Avian leucosis complex Two somewhat similar diseases:				
Lymphoid leucosis	Leucosis virus	Shrinking of combs and wattles. When bones affected the bird walks with a jumpy gait	None	Breeding of resistant strains.
Marek's disease (MD)	MD virus	Blindness. Paralysis of legs and wings	None	Vaccination at the day-old stage.
Fowl pox	Virus	Typical pox lesions	No effective treatment	Vaccination provides a complete control.

Newcastle disease	Virus	Very infectious. Rapid breathing, gurgling noise in throat without discharge of mucus from mouth and nostrils. May be some paralysis	No effective treatment. All birds should be slaughtered after outbreak.	Vaccination at 6-month intervals; first at 8 weeks. Also good sanitation.
Infectious bronchitis	Virus	Occurs in chickens. Rattling in throat, gasping, nasal discharge, watery eyes, depression	Sulphonamides and antibiotics are useful	Vaccination, using a polyvalent vaccine.
Protozoal				
Coccidiosis	*Eimeria spp*. (8)	Droppings watery. Spots of blood may be detected. Chicks droop, reduce feed intake; they may huddle	Sulphadimidine or sulphaquinoxaline in water for 3 days; cease use for 2 days; then use again for 3 days.	Sanitation. No overcrowding Prevent contamination of drinking water. Use a broad spectrum coccidiostat in feed for first 12 weeks

layers and erodes innate resistance to disease (Daghir, 1995a).

The most efficient method of controlling mycotoxins is to prevent the development of fungi in stored feedstuffs. Propionic acid and ammonia can be used as mould inhibitors. Producers are advised to ensure that their home produced, stored feeds are not infected with moulds and that they purchase feeds from reputable suppliers.

Other Forms of Ill-Health

Poultry often exhibit vices such as cannibalism and egg-eating that cause mortality or decrease productivity.

Cannibalism

This may commence as toe-pecking in chicks, feather-pecking in growing birds or vent-pecking in egg-layers. Once blood is drawn the trouble begins and the victim is often killed. Toe-pecking may start among very young chicks; feather-pecking can happen at any age but often occurs when new feathers are forming either during growth of or after a moult; vent-pecking often begins if a hen has a prolapse. The causes of cannibalism are obscure, but it may be due to a deficiency in the diet or to sheer boredom. The feeding of pelleted rations may encourage it. If cannibalism occurs the nutrient content of the rations should be checked, as should the feeding management. The scattering of pelleted feed on the floor may help as this causes the fowls to scratch and this to some extent relieves their boredom. Hanging bunches of green feed in the pen will also give them an additional occupation. In order to check cannibalism it may be necessary to debeak the birds. The top mandible is cut back to the quick using a sharp instrument.

Egg-Eating.

This often occurs when shell-less eggs are laid or eggs are broken in the nest. Preventive measures include a check on the nutrient content of the rations to ensure that eggs with good-quality shells are laid, darkening the nest boxes and taking adequate managerial measures that reduce the likelihood of egg breakage.

Management

Breeding Stock

The problems associated with large-scale breeding and hatchery management in the tropics are discussed by Daghir & Jones (1995). They are somewhat different from those of the small producers, discussed in this chapter.

Not all small poultry farmers breed their own replacements. Those who do must keep very adequate records and selection should be for performance and health. The major traits to consider are age at coming into lay, annual egg production, weight of eggs, hatchability, viability of chicks, daily liveweight gain, mature weight, efficiency of food conversion and adult viability.

The fold system of management is suitable for individual mating and the semi-intensive system for flock mating. Trap-nesting of the hens may be practised. That is, each next box is constructed so that the hen shuts herself in as she enters and has to be released. In this way the productivity of each hen can be recorded. Group recording may be more desirable where mass selection is practised. It is certainly cheaper.

Eggs for Hatching

If hatchability percentages of above 65% of all eggs set are to be obtainedand this is generally considered to be a satisfactory minimum percentagethen care must be taken in the selection of suitable fertile eggs, in their handling before incubation and in their incubation.

Infertility attributable to the cockerel may be due to a variety of causes. The bird may not be sexually mature or may be too old. Maximum sexual vigour is not usually attained until cockerels are 7 or 8 months old, although they may start to mate at a much earlier age. It usually declines after they are 2 years of age. The ratio of cockerels to hens may be incorrect. The normal ratio is one cockerel to 1215 hens with the higher ratio

used in flock mating. Cockerels also exhibit preferences, and in a breeding pen where there is only one, he may neglect certain hens. Finally, the cockerel may be infertile for a variety of genetic, nutritional, health or climatic reasons. Fertility declines at high ambient temperatures. Some hens may also be infertile. Of particular importance is the effect of vitamin and mineral deficiencies in the rations on fertility. Breeding birds must receive nutritionally adequate diets if they are to remain fertile. Even if the eggs of nutritionally deficient hens are fertile the deficiency may be the cause of high embryonic mortality or the hatching of weak chicks.

Fertility depends very largely on the number and viability of the sperm produced by the cockerel and on the time relationship between mating and ovulation. Fertile eggs can be laid within 30 hours of mating, but maximum fertility, which obviously depends upon the activity of the cockerel and the viability of his sperm, is not usually attained until the fifth day (26 days) from initial mating. Sperm may retain their viability in the female tract for as long as 32 days, but the usual range is 1114 days, so that when the cockerel is removed from the hens a decrease in fertility is evident by the sixth day and the decrease is very large by the tenth day. Newly laid eggs should remain fit for hatching for up to 7 days provided that they are kept at a temperature of 13°C and at a relative humidity of 6070%. If eggs are kept at a higher temperature their fertility and hatchability rapidly decrease. This fact is obviously of very great importance in the tropics where the mean annual ambient temperature is approximately 27°C. If eggs are not to be incubated immediately then some provision must be made for their storage at lower than the normal ambient temperatures and preferably within the range of 1022°C. However, eggs must not be stored in a refrigerator as this practice also reduces their fertility.

Considerable agitation during transit before incubation lowers hatchability, but the effect is considerably reduced if the eggs are allowed to stand at rest for 24 hours before transit takes place. Air transport at heights up to 12 000 m does not affect hatchability, though any vibration, sudden chilling or a sudden reduction of air pressure does have an effect.

Care must be exercised in the selection of eggs for incubation. Too small or too large eggs should not be used, neither should poor-shelled, misshapen, dirty or cracked eggs. Dirty eggs may be washed with warm, clean water. Eggs which are visibly porous are particularly unsuitable for incubating in hot, dry climates.

Hereditary defects are perhaps not as common as might be supposed. A number of deformities and monstrosities which were formerly considered hereditary in origin are now known to be due to other causes. Nevertheless at least 20 lethal mutations have been recorded and probably much of the malpositioning of the chick in the shell, which is such a potent cause of unhatchability, may be directly due to hereditary factors.

Several diseases are passed through the egg, but only a few affect either fertility or hatchability. The commonest disease, or at least the best known one, is bacillary white diarrhoea (BWD) which causes the death of a certain number of infected chicks in the shell and of a great number not long after hatching. It is therefore advisable to obtain eggs for hatching purposes from tested adult stock.

Incubation

Eggs may be naturally or artificially incubated. The incubation period for fowls is 21 days. The method used does not affect the quality of the chicks hatched.

Natural Incubation

It is by natural incubation that most chicks of indigenous breeds are produced in the villages. The village hen, sitting on the usual clutch of some eight to ten eggs, needs little food and even less attention. However, the results are usually rather poor, and if the incubating hen was only given a fraction of the care normally bestowed on an artificial incubator, major benefits would accrue. The principal requirements for a 'sitting hen' are a plentiful supply of clean drinking water, a subsistence feed supply, protection against insect pests and vermin, and on hatching, protection of the chicks from predators. The nest should be placed in some quiet, shaded cool corner at ground level and should be enclosed so that the hen can leave it only when permitted. This should be each morning, for about 10 minutes as soon after dawn as is convenient, and again in the evening. During these times the hen should be fed grain and provided with fresh water to drink and a sand-bath in which to dust herself. She should be left undisturbed after the eggs have started to chip and be allowed to move off the nest into her breeding quarters at will. Chaff, sawdust or sand make the best bedding. In very dry climates the nest should be dampened daily. Before the hen sits on the nest, both she and it should be liberally dusted or sprayed with an insecticide.

Artificial Incubation

Large-scale commercial hatcheries equipped with various types of automated or semi-automated artificial incubators are now operating or being organized in almost all tropical countries, either by the government or by private enterprise. At the same time the age-old artificial hatching systems are still employed, particularly in Southeast Asia, and small artificial incubators are increasingly used by nascent specialist poultry-keepers, despite their relative inefficiency. The old artificial hatching system used by the Chinese is well described by Thuraisingham & Wah (1971). The results obtained by this system compare quite well with those recorded from modern incubators, hatching rates of 7585% being normal. Eggs no more than 2 days old, of uniform size and shape, are first warmed for 20 minutes to 2 hours in the sun or on a tray over a charcoal fire. The temperature of the egg is checked by the skilled operator by placing it against his cheek, nostril or upper eyelid. The eggs are then packed in sacking in batches of approximately 100, the sacks being placed in layers in cylindrical bamboo baskets, approximately 0.8 m deep and 0.6 m in diameter, that stand in wooden boxes and are insulated on the outside with rice husk and on the inside with paper. Twice a day the eggs are removed and turned, eggs with dead embryos, recognizable by a change in shell colour, being discarded. Hen eggs are 'candled' on the third and eleventh days and duck eggs on the second and fifth days. Candling is accomplished by passing a beam of light through the egg in such a manner that surrounding light is excluded. Infertile eggs show up as clears, dead germs are seen as a dark spot of varying size and degree of intensity, whilst live ones cast a shrimp-like shadow from which radiate blood vessels. Hatchable eggs are uniformly dark with a distinct air-space at the broad end of the egg, while dead embryos appear to have an air space at both ends of the egg. Hen eggs are removed from the baskets on the eleventh to twelfth day and duck eggs on the fifteenth to sixteenth day. The eggs are then placed in hatching beds, consisting of wooden shelves covered with rice husk. The eggs are covered with layers of matting and the operator removes or adds to the layers of matting in order to keep the temperature around the eggs constant. Temperature testing is by the 'cheek, nostril or eyelid' method. Turning is carried out four times a day, the middle eggs being moved to the outside to help maintain a constant temperature. On hatching the chicks are placed in shallow bamboo baskets to dry. Each incubator basket will hold up to more than 1000 hen eggs, the operation being large-scale in concept.

Artificial incubators can now be purchased to suit almost any circumstance and, if obtained from reputable firms and operated strictly in accordance with the maker's instructions, they should perform admirably. Very small incubators are particularly sensitive to adverse surroundings and the instructions concerning initial heating and the maintenance of correct humidity and temperature need to be intelligently interpreted and meticulously observed. The large incubators, and especially the mammoth types, carry such valuable loads that common prudence demands that they should be in the charge of trained operators and be provided with an alternative power supply.

During incubation the essential air conditions are that there should be sufficient oxygen in circulation to supply the needs of the growing embryo; that the carbon dioxide resulting from embryonic metabolism should not be allowed to accumulate; that relative humidity should be such as to allow not more than 10% of the water content of the eggs to be lost; and that the temperature should be such that life within the egg is maintained at an optimal level.

In the tropics the maintenance of optimal humidity is usually more difficult than the maintenance of optimal temperature. In small incubators with a good air circulation a relative humidity of approximately 58% is required at 38.9°C up to the eighteenth day, but thereafter and until the chicks are hatched a relative humidity of 70% is required. In larger, forced-draught incubators the temperature should be 37.8°C. The variation in temperature should be no more than 0.6°C. In large incubators with unassisted air circulation the usual temperatures recommended are 38.3°C during the first week of incubation, 38.9°C during the second week and a maximum of 39.4°C during the final week. The incubator's thermostat should readily make the minor adjustments necessitated by moderate changes in ambient temperature, but when diurnal variations are large the thermostat may not respond with sufficient speed to give optimal results. It is therefore advisable to site the incubator in a well-insulated room or, if possible, in an air-conditioned room. Such action does not necessarily assist in regulating humidity as there are tropical climates in which relative humidity will vary by as much as 55% during 24 hours. Under these circumstances the incubators must be fitted with an egg-moistening mechanism or the incubation room be provided with humidity controls.

If the correct oxygen/carbon dioxide level is to be effectively maintained there must be a passage of fresh air not only over but also around the eggs, and therefore all air pockets must be eliminated. This is facilitated by positioning the incubator away from the walls and corners of the room so that there is space for proper ventilation.

Incubating eggs should preferably be turned at least five times daily up to the eighteenth day. All modern incubators provide some method by which this can be easily accomplished. If turning has to be done by hand it may be impractical to turn the eggs five times a day, but it must be done no less than twice.

During the fourth to the seventh day and on the sixteenth day of incubation it is customary to check and remove all infertile eggs and those with dead embryos. This is done by 'candling'. Eggs are transferred from the setting trays in the incubator to the special hatching trays on the eighteenth day. Hatched chicks should be transferred from the incubator to whatever type of special tray or basket can be provided.

Strict hygiene must be practised during all phases of incubation. After every hatch all the equipment should be scrubbed with a disinfectant.

Brooding

Under backyard conditions the hatched chicks are reared and protected by the broody hen. Incubated chicks must be artificially brooded. At this stage in their life chicks are very vulnerable and losses during brooding are often excessive. If the brooding methods are satisfactory mortality in chicks should not exceed 5% during the first 8 weeks of life.

During the last stage of incubation the chick absorbs sufficient nutrients to last it for at least the first 48 hours of life. This is why day-old chicks can be transported in boxes for long distances. Nevertheless, it is a good managerial practice to make some food available soon after hatching.

In the tropics, if newly hatched chicks are left in the hatching tray of the incubator for 24 hours the relative humidity should not be allowed to rise above 55%, as high humidity combined with high ambient temperature has a most debilitating effect on chicks. The most suitable practice is to transfer the chicks from the incubator to the brooder as soon as they have dried out. If chicks hatched under hens are to be artificially brooded they should not be transferred to the brooder until they are 48 hours old.

It is normal to identify the sex of most chicks before they are transferred to the brooder as the information is of some economic importance. There has always existed the possibility that sex-linked traits could be used to identify the sex of day-old chicks, but such traits are not necessarily correlated with production traits. Most chicks in the immediate past have been sexed by manipulation and examination of the cloaca, with or without instrumentation. There is, however, a new interest in utilizing sex-linked external traits.

There are many designs of brooder. The basic requirements are that sufficient heat should be applied in a specific part of the brooder known as the hover to keep the chickens warm without their crowding together, that the brooder should be well lighted and ventilated, and that sufficient total space should be available to allow for growth in the chickens. The initial temperature below the hover should be 35°C at 5 cm from the floor, and in the tropics the hover temperature should be reduced by 3°C each week until it equals the mean daily ambient temperature. This should be by the third week as the mean tropical ambient temperature is usually 27°C. This ambient temperature is likely to be somewhat above the optimum for the chicks at the end of the brooding period. Good light is desirable as it encourages the chicks to start feeding. In the rainy season in the tropics it may be necessary to provide some artificial light in the brooder during daylight hours. Good ventilation is also desirable, but it is often overlooked when efforts are made to conserve heat. In the tropics it is desirable to provide a brooder with a fine wire-netting floor as this not only allows droppings to be evacuated from the floor area, thus minimizing internal parasitism and disease, but also improves ventilation and reduces the internal temperature of the brooder during the hottest periods of the day. If the brooder has been designed for use in the temperate zone, as is so often the case, then the number of chicks housed should be reduced by at last one-third below the manufacturer's recommendation. The minimum total floor space allowed should be 7 m2 per 100 chicks for an 8-week period. Preferably more space should be allowed. Broiler chicks should certainly be allowed more space100 chicks requiring 10 m2 for a period of 10 weeks. Within the hover area a chick requires approximately 4560 cm2 of floor space so that under a circular canopy 1.2 m in diameter 250300 chicks can be accommodated.?

Types of Brooder

The type of brooder that should be used depends upon the location of the farm, the cost and availability of fuel, the size of the unit and the type of housing available:

• *Floor brooders* heated by electric elements are obtainable. They are clean, easily operated, labour saving and maintain a fairly constant temperature. Infra-red lamps are efficient and allow maximum ventilation. A single 250 W bulb raised 38 cm above the floor level is sufficient to brood 100 chicks. For a smaller number of chicks normal electric light bulbs placed under a canopy will suffice. However, electricity is not always available in rural tropical environments.

• *Kerosene brooders* can be used as an alternative, but they do not maintain such a constant temperature, there is the risk of fire and the fumes can irritate the chicks.

• *Charcoal brooders* are cheap to operate and charcoal is usually readily available in tropical countries.

• *Wood-burning brooders* have also been designed.

• *Large hot-water brooding units*, utilizing hot water from a central installation, can be constructed. The initial capital costs are high, but such brooders are cheap and simple to operate.

• *Battery brooders* operating on electricity or kerosene are available, but they are usually expensive to install and to operate.

A cold brooder should be the brooder of choice for the small poultry-keeper in all except the montane regions of the tropics. In order to breed batches of up to 60 chicks a wooden box measuring approximately 60 × 60 × 45 cm is required. One half of the top of the box should be hinged so that the chicks can be handled and the box cleaned. At the bottom of one of the walls a 15 cm shutter should be provided so that the chicks can be moved out of the box during the daytime and be closed in it at night. Two methods of insulation may be used.

For the first type rice straw is soaked in water, allowed to partially dry and is then beaten with a wooden block. The whole of the inner surface of the box is lined with this processed straw which is covered by a gunny-sack lining that is nailed to the box to keep the layer of insulating straw in position. Short lengths of internode bamboo, or some other form of pipe, approximately 1.5 cm in diameter, are then fixed in the sides and the top of the box in order to pass through the straw insulation and the sacking material, thus providing ventilation. The pipes in the sides should be fixed about 15 cm above the floor level. Approximately 12 of these ventilators are required and strips of gunny sack should be suspended from the top of the box in front of them so that there is no direct draught on the chicks. Rice husks are placed on the floor of the brooder.

The second type is even more simple to construct. Strips of fabric are nailed to the roof of the box so that they dangle just above the floor. They should be closely spaced. Ventilation holes are then bored in the wooden sides and the top of the box, no pipes being needed, and the floor of the box is covered with rice husks. If the brooder is indoors then the floor of the box can be made of a fine wire mesh. The box is then placed in a larger wire-meshed floor pen or can be constructed as part of it (Fig. 15.2). The latter arrangement is preferable. The efficiency of this type of cold brooder can be vouched for by one of the authors who has had occasion to use one.

Operation of Brooders.

The desired temperature should be maintained in the brooder for at least 24 hours before the chicks are transferred. Chicks should be counted

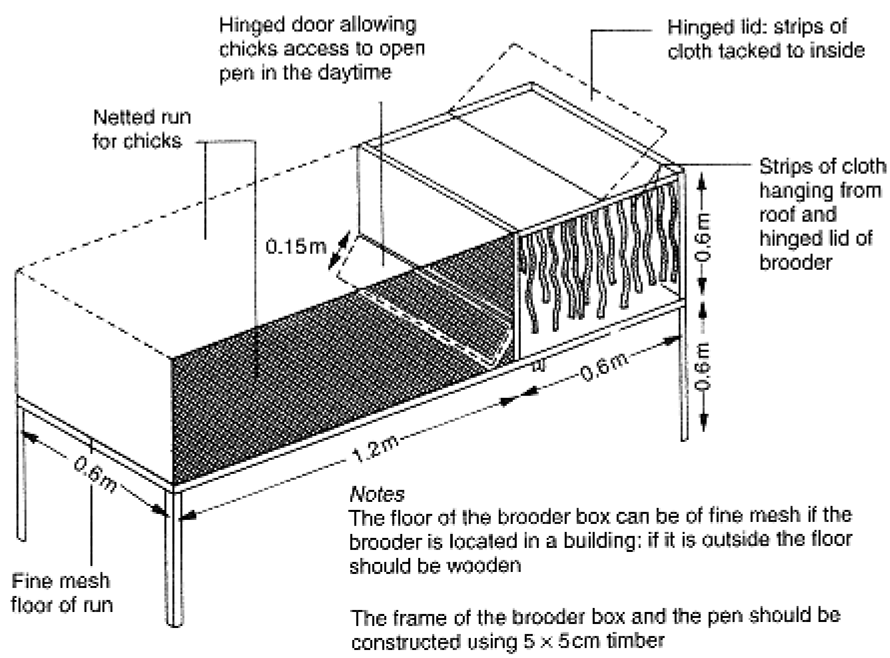

Fig. 15.2
A schematic design of an inexpensive cold brooder suitable for use in the tropics.

and examined before they are placed in the brooder, obviously unhealthy individuals being culled. During the first few days a ring of fine wire mesh will keep the chicks close to the heat source. The ring should be widened daily and removed entirely after 7 days. The distribution of the chicks under the brooder heat source should be continuously checked. If they huddle and chirp the temperature is too low, while if they pant and draw away from the brooder the temperature is too high.

Perches should be available in the brooder house at least by the time that the chicks are 3 weeks old. Details of suitable perches are given in Table 15.8.

Feed and water should be available when the chicks are first placed in the brooder. Feed should at first be fed on sheets of cardboard until the chicks become accustomed to the usual feeders. Feed trough length requirements are shown in Table 15.4. During the first 4 weeks 100 chicks require at least four water troughs each of 2 litres capacity. Later they will require four water troughs each of 5 litres or two of 10 litres capacity. Details of the length of trough required are given in Table 15.5. At first the feed and water troughs should be placed near the heat source. Later they should be placed so that the chicks learn to use all the space that is available in the brooder. In order to reduce feed wastage feeders should never be filled to more than half their total capacity and their design should be such that the chicks cannot get inside them. Chicks should be allowed to empty the feeders completely every 2 or 3 days. At other times, feeders should always contain feed. Sand and/or grit should be fed in separate feeders and green feed can be introduced after the first week. Watering troughs should be placed on wire platforms in order to minimize the effects of spillage and should be designed so that contamination with faeces is reduced to a minimum.

Good sanitation is of major importance in brooders. Buildings and all equipment should be cleaned and disinfected before use. Feed and water troughs should be kept as free as possible of all contamination at all times. The brooder should be separate from other poultry buildings and activities. When chicks are brooded on litter this must be maintained in a dry, friable state and not allowed to become damp.

Chicks of different age and/or breeds should not be housed in the same brooder. This is because older individuals or those of the stronger breed develop at the expense of the younger and/or weaker breed.

Rearing

At 68 weeks of age the growing birds should be transferred from the brooder to a rearing unit. Cockerels are separated from pullets if both

Table 15.8 Perch requirements for different classes of poultry.

Class	Length of perch per 100 birds (m)	Cross-section of perch (cm2)	Height above floor (cm)	Spacing in house (cm apart)
Fowls				
Brooders	10	3.5	25	
Rearing house	1015		61	38
Semi-intensive house				
Light breed	20	5	76	
Heavy breed	2330	5	76	
Turkeys				

Light breed	30
Heavy breed	38

have been reared together and the ration is changed from the starter to the grower type.

The rearing unit may be on range or it may be intensive. On small poultry farms the brooder pen may be used as an intensive-rearing pen. If this is the case then additional space will be required as the birds continue to grow.

Range Rearing

The major advantages of range rearing are that the birds acquire part of their diet by scavenging for herbage, seeds and insects and that they usually remain very healthy. It is only practical if there are no daylight predators in the district. An area with shade cover is preferable to open land and the space requirement is 58 m2 per bird (Table 15.9). A simple building in which the birds can be enclosed at night is required. The night accommodation, even if simply constructed, should possess adequate space, good ventilation, perches for roosting and proper protection against predators and inclement weather. Most housing on small poultry farms does not attain minimum standards of adequacy. Aitkens (1956) described a type of night accommodation for a small number of range poultry, used in Sri Lanka, that would appear to be admirable. The house is about the size and shape of a small bullock cart. The walls are made of woven leaf stalks or reeds, the roof is rainproof and made of woven large leaves and the floor is constructed of slatted bamboo or other suitable materials. This house is hung between two trees and access is provided by a bamboo pole, through a small door placed in one wall. After the birds have gone to roost each evening the door is closed, using the pole, which is then removed to the owner's house. Baffles are placed on the rope slings that suspend the house in order to deny entry to vermin and insects.

Feed and water containers should be available both on the range and in the house. The birds should be moved at regular intervals to a different area in order to avoid a major build-up of internal parasites and disease organisms. Feeders can be closed for part of the day in order to encourage the birds to forage.

An alternative method of rearing on range is the *fold system*. This is a semi-intensive system of utilizing range. Groups of 2550 birds, depending on their size, are confined in a moveable, wired-in run with attached housing that is sufficiently large to accommodate them at night. The unit is moved to fresh ground at frequent intervals, preferably each day. The system allows the orderly use of land, decreases the possibilities of worm infestation and ensures the even distribution of poultry droppings. The stocking rate can also be as high as 1000 birds per ha. It is, however, labour intensive and a considerable amount of equipment is required. The system cannot be used either in the equatorial tropics where the land is often flooded or in the very arid tropics where adequate shade cannot be provided. Details of the construction of a suitable fold unit are given in the section on housing.

Intensive Rearing

This is normally a well-ventilated deep-litter house. In most regions of the tropics the house does not require conventional walls, but there must be some device by which cold, driving rain can be prevented from entry during the rainy season. The space requirements in this system are shown in Table 15.9 and perching requirements in Table 15.8. Feeding trough requirements are shown in Table 15.4. If hanging feeders are used, every 100 birds require four 11 kg capacity feeders.

Management during Rearing

In general, birds that are brooded together should be reared together, but some re-sorting of the birds is likely to take place when they are transferred to the rearing unitsbirds of the same size and weight being kept together and cockerels being separated from pullets. Transfer of birds to rearing units should be accomplished with the least disturbance and should not take place during the heat of the day. Required vaccinations should be accomplished as should deworming at 10 and 18 weeks of age. If coccidiosis is a problem then a coccidiostat should

Table 15.9 Approximate floor space requirements for different classes of poultry in the tropics.

Class	Floor space requirement (m2)
Ducks	
Ducklings up to 7 weeks	
Semi-intensive house	0.14
Adult birds	
Semi-intensive house	0.28
Fowls	
Chicks	
06 weeks of age	0.05 minimum
>6 weeks of age	
Conventional housing	0.14
Controlled environment	0.09
Broilers	0.09 minimum
Rearing stock	
Range	
House	0.14
Range	5.08.0
Intensive	
Light breeds	0.19
Heavy breeds	0.28
Layers	
Semi-intensive house	0.19
Intensive	0.28
Deep litter	0.37
Turkeys	
Poults	
Intensive rearing	0.370.56
Breeders	
Small to large types	
Semi-intensive	
House	0.370.46
Yard	0.370.46
Intensive	0.560.74

continue to be used until the birds are 1216 weeks old. Total mortality from hatching to maturity at approximately

20 weeks of age should be no more than 12%.

Layers

Pullets should be transferred from the rearing to the laying house at 1718 weeks of age. At the time of transfer they should be grouped according to size and stage of maturity. The age at first laying should be between 20 and 24 weeks. If pullets are not laying when they are 24 weeks old then they have probably been mismanaged during the brooding and/or rearing stages.

Major factors that determine the age of pullets at first laying are breed, with light breeds laying at an earlier age than heavy breeds; their nutrition during brooding and rearing, as fast growth is correlated with the rapid attainment of sexual maturity; managerial practice during rearing, as intensively reared birds usually lay at an earlier age than range-reared birds; and on the light regime to which they have been subjected, as decreasing hours of daylight discourage laying while increasing hours hasten it.

There are four major systems used for the housing of laying pullets: semi-intensive, deep litter, slatted or wire floor and battery. Some details of the construction of these are provided in the section concerned with housing.

Semi-Intensive

This is the most common system used by small producers and it is often used by the smaller breeders. The poultry have access to outside runs where they live during the day and to houses where they sleep at night. It is preferable that each house should possess two or more outside runs, so that one or more can be rested while the other is being used. It is also a good practice to spread lime over the land in the pen that has just been vacated, and if there is grass the pen can be grazed by other species such as calves, sheep or goats. It is usual for the birds to be fed and watered in the outside run. Space requirements for feeding and watering are shown in Tables 15.4 and 15.5. The feed and water troughs should be moved at regular intervals. Within the houses sufficient perch space must be allowed and details of requirements are shown in Table 15.8. In addition individual or communal nesting boxes and a broody coop are required. The semi-intensive system requires more land and labour than most of the other systems and the capital cost is quite high, but pullets usually thrive.

Deep Litter

The housing for this system is the simplest to build and operate. The floor can be constructed of rammed earth or concrete, but in the wet tropics it is preferable to use concrete. A variety of different types of litter can be used. Nesting boxes and a broody coop are required in the house as are water and feeding troughs. Troughs are best suspended above the litter. If runs are provided it can be used as a semi-intensive house.

Slatted or Wire Floors

Houses constructed with slatted or wire floors are said to be cooler than other types of house. However, building costs are high and management is more complicated. Rats are often a major problem.

Batteries.

This is probably the most efficient system as egg production and feed conversion efficiency are high when fowls are housed in battery cages. Little land is required, recording is simple and batteries can be very labour saving if they are equipped with automatic feeding, watering and cleaning devices. They are particularly useful where light breeds are utilized, land is expensive and labour is relatively expensive, as is the case in some countries in Southeast Asia. Batteries do however, have disadvantages. They are relatively costly to install, the number of cracked eggs may be quite high and vermin and insects can be a nuisance. Battery housing systems can also be criticized on bird care, health and welfare grounds. Production efficiency can be sought at too high a cost in other values. Costs of construction can be substantially reduced if the cages are constructed from bamboo and/or rattan as is often the case in many Southeast Asian countries (Fig. 15.3).

Nesting Boxes

Whatever the type of housing used, nesting boxes should be installed before the first eggs are laid. Otherwise eggs may be laid on the floor of the house or elsewhere and this increases the possibility of them being broken and becoming dirty. Cracked or broken eggs are an economic loss and encourage the vice of egg-eating, while dirty eggs increase production costs as they have to be cleaned.

Nesting boxes can be individual or communal, conventional or unconventional (Fig. 15.4). One individual box is required for every six pullets in the pen. These boxes should be located in the coolest and darkest area of the house, they should be raised 0.6 m from the floor, the top should be constructed with a sharp slope otherwise birds will perch on and foul them, and their floors should be covered with 58 cm of a litter

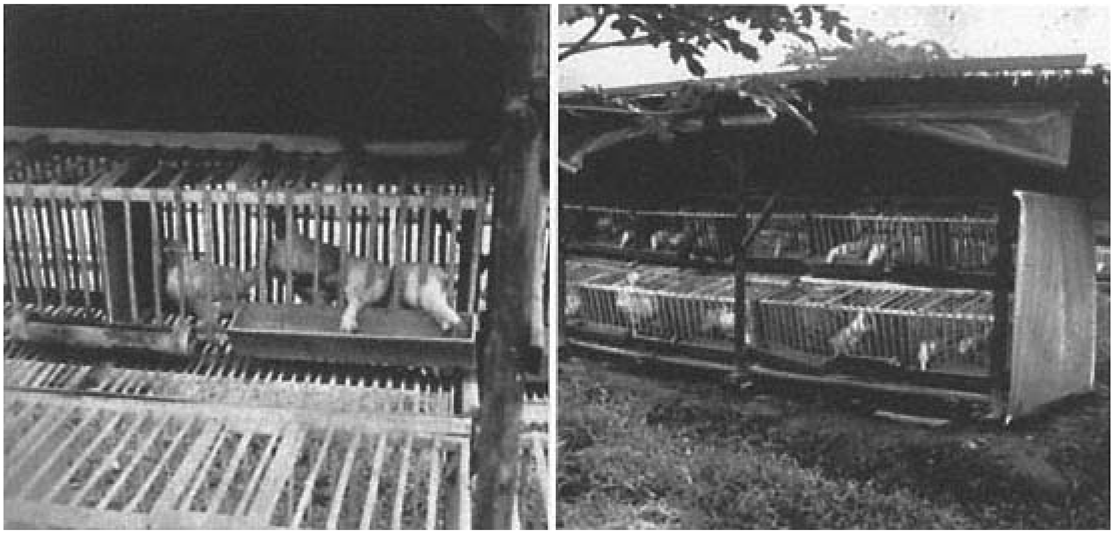

Fig. 15.3
The use of bamboo in a locally constructed battery unit located near Palembang, southeast Sumatra, Indonesia.

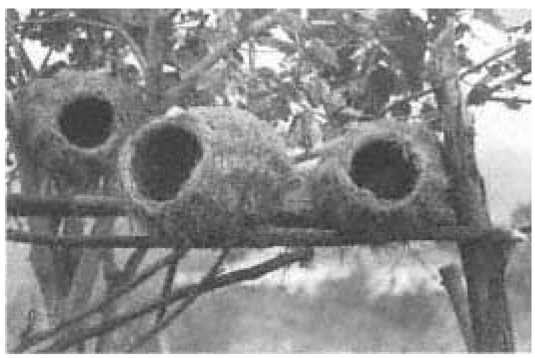

Fig. 15.4
Unconventional nesting boxes in Swaziland.

such as rice hulls or sawdust. It is also advisable to construct a small alighting perch just outside the entrance to the nest, and nests should be fitted with some device such as a bar so that they can be closed. The minimum space allowance for nesting birds should be 0.1 m2. Nesting boxes should be constructed in such a manner that egg collection is facilitated. Usually they possess a hinged top. In battery systems where the living space is also the nesting space the minimum cage sizes recommended in the temperate zone are as shown in Table 15.10.

Table 15.10 Minimum recommended cage sizes for battery systems in the temperate zone.

	Size		
	Width (cm)	Depth (cm)	Height (cm)
Single birds	30	43	46
Two birds	41	43	46
Three birds	51	43	46

With gangways 1.1 m wide more than one row of cages is used. The cages are normally constructed of stout galvanized wire. The floor slopes 10 cm from the back of the cage to the egg cradle which extends some 15 cm in front of the cage. Underneath is a tray for droppings, and the food and water receptacles are located outside the cage. The authors recommend that in the tropics only cages for single birds should be used and that the cages should be somewhat larger. At least 0.14 m^2 of floor space should be allowed per bird.

Details of requirements for feed and water trough space are given in Tables 15.4 and 15.5. Where hanging feeders are usedand these are recommended in deep-litter housesthey should be suspended at a height that is approximately level with the backs of the birds.

When pullets are transferred to the laying house the ration is changed to the laying type. Grit must always be available and the feeding of at least 5 kg of green food per 100 birds per day is desirable.

Broodiness

Broodiness is the instinct to incubate eggs and is an inherited trait. Heavy breeds go broody more often and for longer periods than light breeds of birds. In some of the new breeds the trait has been reduced by genetic selection. As broody hens cease to lay but take up nesting space they should be removed and placed in a special broody coop. This should be raised off the floor and be well ventilated. A slatted floor, together with wire and/or slatted sides, is desirable. Special feed and water containers are required in the coop. There is usually an interval after broodiness before egg laying is resumed.

Artificial Light

Under natural conditions egg laying is correlated with length of daylight and artificial light is used in the temperate zone to even out egg production and to prevent pullets moulting in their first year. In the tropics where daylight length does not alter appreciably throughout the year the problem of seasonal egg production is not so acute. It is recommended that under these circumstances the most suitable management practice is to provide additional hours of light before dawn and after dusk in order to encourage the hens to eat during the cooler periods of the 24 hours. This may be achieved by fixing 40 W electric light bulbs in position 2 m above the floor. One bulb should be sufficient to illuminate 18 m2 of floor space.

Moulting

This condition occasionally occurs in birds during the first year of lay. It is due to stress. The symptoms are cessation of egg laying, shedding of feathers and drying up, paleness and reduction in size of the comb. The condition may last for a few weeks or even for months. Moulting can usually be avoided by careful handling of the birds and by the avoidance of undue stress.

During their second year it is natural for most pullets to moult and cease egg production. This is one reason why it is normal for commercial egg producers to keep their pullets for only 1 year of egg laying. In many tropical countries, where the price of poultry meat is higher than it is in most temperate countries, it is usually even more economic to sell all pullets after 1 year of egg production.

Egg Collection

Eggs should be collected at least twice a day and records of the number of eggs collected should be kept. The eggs should be stored in a cool place before they are marketed.

Broiler and Other Meat Birds

In a majority of tropical countries the broiler industry has developed very rapidly since the 1970s, but there are still countries or regions within countries where meat is produced from culls or from the surplus cockerels originating out of the egg-laying flocks.

The major advantages of producing meat from poultry are that they require limited areas of land and that they are very efficient converters of feed into meat. The disadvantage is that poultry often compete with humans for feed supplies.

Where feed supplies are adequate the development of a broiler industry is indicated. Broilers are meat-type chickens that have been specially bred for marketing at an early age. They are usually sold when they weigh about 1.9 kg in North America, but in many Southeast Asian countries broilers are marketed at a smaller size (>1.4 kg) and at a younger age. The production of broilers is therefore a specialized industry which is conducted separately from egg production.

For a successful broiler enterprise a breed must be used in which both sexes exhibit fast growth and early feathering, that possesses a high efficiency of feed conversion, preferably less than 2.2:1 and whose flesh colour must conform to local prejudices. In addition the adult pullets must be reasonably good layers so that the chicks can be produced and purchased at an economic price.

The only breeds that possess all these characteristics are the new hybrid broiler breeds produced by the international large-scale breeders. Nevertheless, in countries where the new hybrid breeds are not yet available or are considered too expensive, first-cross birds that are not quite so efficient may be used for broiler production. For example, the first cross White Leghorn × New Hampshire will produce a 1.4 kg broiler at 11 weeks of age with an efficiency of conversion of 3:1.

For broiler production it is usual to accommodate the birds in large deep-litter houses. The more broilers that are housed together the more economic the operation becomes, so that broiler production is essentially a large-scale industry. The minimum size of an economic unit is probably 1000 chicks, but there are many smaller broiler production units in tropical countries.

Some details of the construction of suitable deep-litter houses are provided later. It is normal to breed the chicks in a section of the house that will accommodate the broilers so that they do not have to be moved. They will require a minimum of 9 m2 floor space per 100 birds (Table 15.9), and the broiler house should be sited where maximum advantage can be taken of prevailing winds for ventilation purposes unless environmentally controlled accommodation is to be used. The type of construction and the materials used in construction should be suitable for the climatic environment. It should be possible to have a throughput of four to seven batches of broiler chicks per year in any one house, depending upon the efficiency of the operation. The litter, which should be approximately 8.0 cm deep, should be cleaned out between batches and the building and all equipment sterilized. If suitable chemicals are not available for the sterilization of equipment then thorough washing followed by exposure to bright sunlight must suffice.

The nutrient content of the ration is critical in broiler production. It must provide all the essential food required for rapid growth and it is normal to add antibiotics and possibly other additives. It is best fed in the pelleted form or as a crumble. A coccidiostat should also be included in the ration.

It is necessary to reduce stress to a minimum so the chicks should be quietly handled at all times. In the tropics environmentally controlled accommodation is the most suitable, but in its likely absence efforts should be made to reduce heat stress. One desirable managerial practice is an arrangement that allows the chicks to feed when ambient temperatures are lowest, i. e. at 03.00 to 05.00 hours in the morning and in the evenings after dusk. In order to achieve this the broiler house must be artificially illuminated from 03.00 hours in the morning and for two hours after sunset, and darkened during the hours when daily ambient temperatures are highest, i.e. between 12.00 and 16.00 hours. This managerial practice is only possible, of course, where houses can be darkened during daylight hours without reducing ventilation.

Caponization

This is a technique that makes the flesh of old birds more succulent and tender and is one that has been used for a very long time. In the past the caponization of cockerels was carried out by surgical operation. An incision was made on either side of the body and the testicles removed. Chemical caponization, using a hormone implanted in the back of the neck, is now the normal method. With the advent of the broiler industry caponization is now less commonly performed than it was in the past. One disadvantage of caponized cockerels in tropical countries is that they are more susceptible to heat stress than uncaponized birds.

Housing

Poultry housing should provide adequate shelter, a healthy and comfortable environment and reduce labour requirements to a minimum.

General Considerations.

Requirements for housing differ from one region of the tropics to another. In the wet tropics protection is required against rain, high humidity and moderately high ambient temperatures, whereas in the dry tropics protection is required against very high and quite low ambient temperatures and possibly dust storms.

Location

If there is a choice of location all buildings should be sited on the highest ground not subject to flooding and where advantage can be taken of any prevailing breezes. All buildings should if possible face in the same direction and preferably be eastwest orientated. There should be a distance of at least 12 m between individual buildings in order to reduce the possibilities of disease and parasite transference from house to house. If possible the brooder house should be completely separate from other buildings. The feed room should be centrally sited and the egg-storage room located adjacent to egg-laying units.

Floors

The most suitable material for the floor is concrete, but wooden or rammed earth floors can be used.

Walls

In the wet tropics the walls of all except environmentally controlled houses should be open. Heavy-gauge netting wire or expanded metal grilles are the most suitable materials with which to screen buildings. Screening is essential as it keeps out the larger vermin and wild birds. The screened walls should be provided with some form of protective cover that would normally be rolled up or pulled to one side, but which can be used during the rainy season to protect the birds and, in the case of deep-litter houses the litter, from driving rain. Split bamboo, reed curtains or blinds are very suitable or heavy-duty plastic sheeting can be used. In dry climates the walls should be solid, at least to above the door level. Brick or clay and straw are very suitable materials. In such houses it is necessary to make adequate provision for ventilation. Although external temperatures may rise rapidly during the daytime, internal temperatures will rise more slowly in such houses.

Roofs

In the wet tropics high-pitch roofs are required that will shed heavy rain. They should overhang the eaves by at least 1.0 m. The height of the roof should be at least 3.7 m at the eaves. In the dry tropics the roofs can be flat or have a low pitch, but they should be as high off the ground as is practicableat least 3.7 m. The main roofing materials available are corrugated iron and thatch, although in a few tropical countries such as Mauritius and Indonesia clay tiles are cheap and can be used for roofing. Corrugated iron is the least suitable, and if it is used it should be painted with aluminium paint on the upper side and with black paint on the lower side. Thatch is very suitable, but as it has to be replaced quite frequently maintenance costs are high. It also has the disadvantage that it harbours vermin. A wide variety of thatching materials are available in the tropics, including all types of grasses and reeds and many types of palm thatch, including doum palm (*Hyphaene thebaica*) in the dry areas of East and Northeast Africa, coconut palm and nipa palm (*Nypa fruticans*) in Southeast Asia and oil palm (*Elaeis guineensis*) in West Africa, Southeast Asia and elsewhere. A corrugated iron roof can be combined with thatch which acts as an insulating material under the corrugated iron. There should be a gap of approximately

10 cm between the corrugated iron and the thatch.

Dimensions

The dimensions of houses will obviously vary in accordance with the needs of the poultry farmer. In general, houses approximately 10 m wide and with 1.2 m internal passages have been found to be practical and useful. They can, of course, be any length that is required.

Methods of Reducing Heat Stress

Where environmentally controlled houses cannot be utilized for economic reasons or because adequate services are not available, the poultry farmer should still attempt to reduce the possibility of heat stress in housed birds. The first consideration is adequate ventilation. In the wet tropics houses without walls should provide adequate ventilation and some degree of alleviation of heat stress on birds from improved air circulation. In the dry tropics, where the birds are enclosed, proper ventilation of the house is essential. As hot air rises, ridge ventilation is a necessity. If economic and service circumstances allow it, forced-air fans should be used.

The planting of large shade trees adjacent to and overhanging the houses will help to keep the birds cool in hot weather, although this practice is not recommended in hurricane zones. The planting of grass lawns or other vegetation around the houses can also be of considerable assistance, particularly in the dry tropics, where the vegetation will have to be irrigated.

Sprinklers can be sited on corrugated iron roofs and this can be a very effective method of cooling houses. The water that drips off the roofs should be used to irrigate grass or other vegetation around the houses and this can be cut and used as a green feed.

Misters or foggers are particularly useful in batteries. A water pipe with fine nozzles fixed at appropriate intervals is hung above the cages and used when ambient temperatures risein particular during the early afternoon.

If pipes are used for perches cold water can be circulated through them. This is quite an effective method of reducing heat stress in poultry.

Fold Houses and Pens

The runs are made of 1.3 cm mesh 14-gauge wire netting set on a framework of light but tough wood. To house 50 birds the frame should have a floor space of 9 m2. The house can be of the slatted ark type that is widely used in the temperate zone, modified for use in the tropics. It should stand 30 cm above the ground. The floor is made of slats approximately 2.5 cm wide and spaced 2.5 cm apart. A moveable wire netting floor is fitted 10 cm below the slats to prevent the entry of vermin. The walls, which also form the roof, converge steeply to the ridge about 1.2 m above the slats. The one wall can be enclosed, but the other should consist of a door made from a frame covered with 1.3 cm mesh, 14-gauge netting in order to permit free circulation of the air. A bamboo or plastic roll-up flap or curtain should be attached to the open wall so that protection can be provided during heavy rain. The wall-roof can of course also be made of thatch.

Fold houses are only practical in areas devoid of major predators.

Semi-Intensive Houses

It is advisable under tropical conditions to utilize houses that accommodate approximately 50 adult birds (Fig. 15.5).

The wire out-runs should be at least 1.8 m in height and be made of 1.3 cm heavy-gauge galvanized wire netting. The top-most 13 cm should be left slack so that it does not provide birds with a steady foothold, and the wire should be buried 30 cm into the ground to stop vermin burrowing under. This precaution is particularly necessary where the mongoose is a local predator.

The floor-space requirements in such a house are shown in Table 15.9. Fifty birds require approximately 9 m^2 of open floor space. Details of the type of floors, walls and roofs required have been given in a previous section.

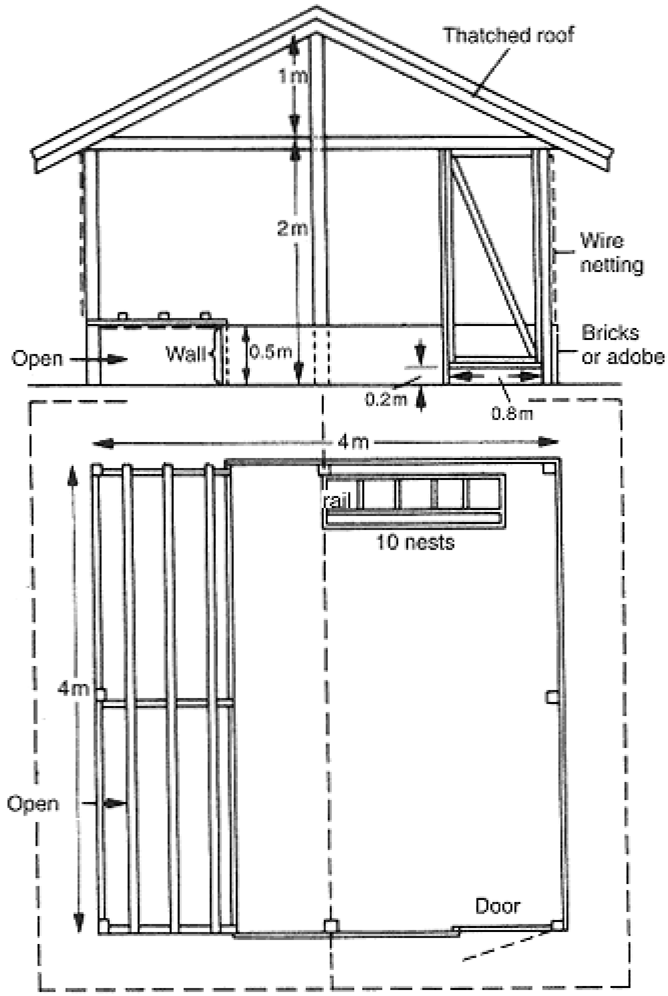

Fig. 15.5
Elevation and plan of a prototype poultry house for 50 laying hens.

Deep-Litter Houses.

For the small poultry-keeper who cannot afford a controlled-environment deep-litter house the main considerations are that the house should be cheap to construct, that birds are not over-crowded in the house and that the litter is not allowed to become damp. Space requirements are given in Table 15.9 and general information on the type of building required in a previous section.

The maximum depth of the litter should be no more than 30 cm. The normal requirements of mature birds are litter with a depth of 1013 cm accumulating to 2023 cm. For chicks the initial depth of the litter should be no more than 58 cm, but it can gradually be built up as the chicks grow.

As stated previously the floor of the deep-litter house can be rammed earth, wood or concrete, but concrete is preferable. There must be a retaining wall of concrete or brick around the floor at least 30 cm high. If division walls are required inside the house the most suitable material to use is expanded metal grilles, as these allow for ventilation but are also quite rigid.

Many materials can be used as a litter including peat moss, wood shavings, sawdust, rice husks, chopped maize, sorghum or millet stalks, chopped rice straw, dried leaves, groundnut

shells, or even dried cow manure. If damp patches occur in the litter it should be turned and treated with burnt lime or superphosphate at the rate of 1 kg for every 1.5 m2 of litter. The advantage of using superphosphate is that unlike lime it does not release ammonia from the litter. If careful attention is given to the litter it will develop dry, crumbly characteristics after a few weeks, when new material can be added. When litter is properly managed it should last for a long period, but as a precaution against the transmission of disease it is normal procedure to clean out the litter and to renew it when a new batch of birds is brought into the house.

The litter makes a manure that is an excellent fertilizer. In 1 year 30 birds will produce approximately 1 t with nitrogen, phosphoric acid and potassium contents of 3, 2 and 2%, respectively. The production of this manure improves the economics of deep-litter poultry production and this factor must be taken into account when deciding which poultry managerial system to use in areas where organic fertilizers have a considerable market value.

Details of feeding, watering and perch requirements are given in Tables 15.4, 15.5 and 15.8.

Battery Houses

Data on the cages have already been provided. Requirements are that the house should be well ventilated, lighted and vermin-proof. On small farms a house with a concrete floor, a roof and wire-mesh or expanded metal sides would meet these requirements, but the birds will not perform quite as efficiently as they will in an insulated, controlled-environment house. In such a house the batteries of cages can be serviced by automatic watering, feeding and cleaning devices that if powered from a reliable source and properly serviced are very labour saving and efficient.

Controlled-Environment Houses

These are houses in which the optimal environment is provided for whatever form of production is planned. Ambient temperature, humidity, air movement and light must all be controlled. The building must therefore afford effective insulation from the external environment. As this is likely to be expensive in terms of capital, the cost must be distributed over a large bird population in order to make it an economic proposition. Therefore all other factors being equal, a large unit is more economical to operate than a small one. However, the larger the unit the lower the level of husbandry inevitably becomes and the chances of introducing disease, as well as the consequences of doing so, increase. The size of the plant must therefore be closely related to the competence of the management, the skill of the stockman and the reliability of available services. It is generally agreed that broiler units housing approximately 15 000 chicks and layer units accommodating 5000 laying hens are suitable and economic. Minimum temperatures in broiler units should be of the order of 21°C, while in layer units they can be of the order of 1013°C, but for maximum production ambient temperatures in these units should be higher, as discussed earlier. Relative humidity should be in the range of 3570%. Light should be of even intensity throughout the building.

Equipment

Designs of some simple and suitable feeding and watering devices are shown in Fig. 15.6. Oluyemi & Roberts (1979) have provided additional designs of feeding and watering devices that may be used in the wetter tropics.

Ducks

Domestic ducks, like fowls, are raised throughout the tropics, but they are most numerous in regions of high rainfall, in riverine areas, in deltas and in coastal districts. FAO (1995) estimated that there were a total of 681 million ducks in the world in 1994; at least one-third of them raised in the rice growing areas of Southeast Asia (Table 15.11).

The total number of domestic ducks in the world is, however, small compared with the total

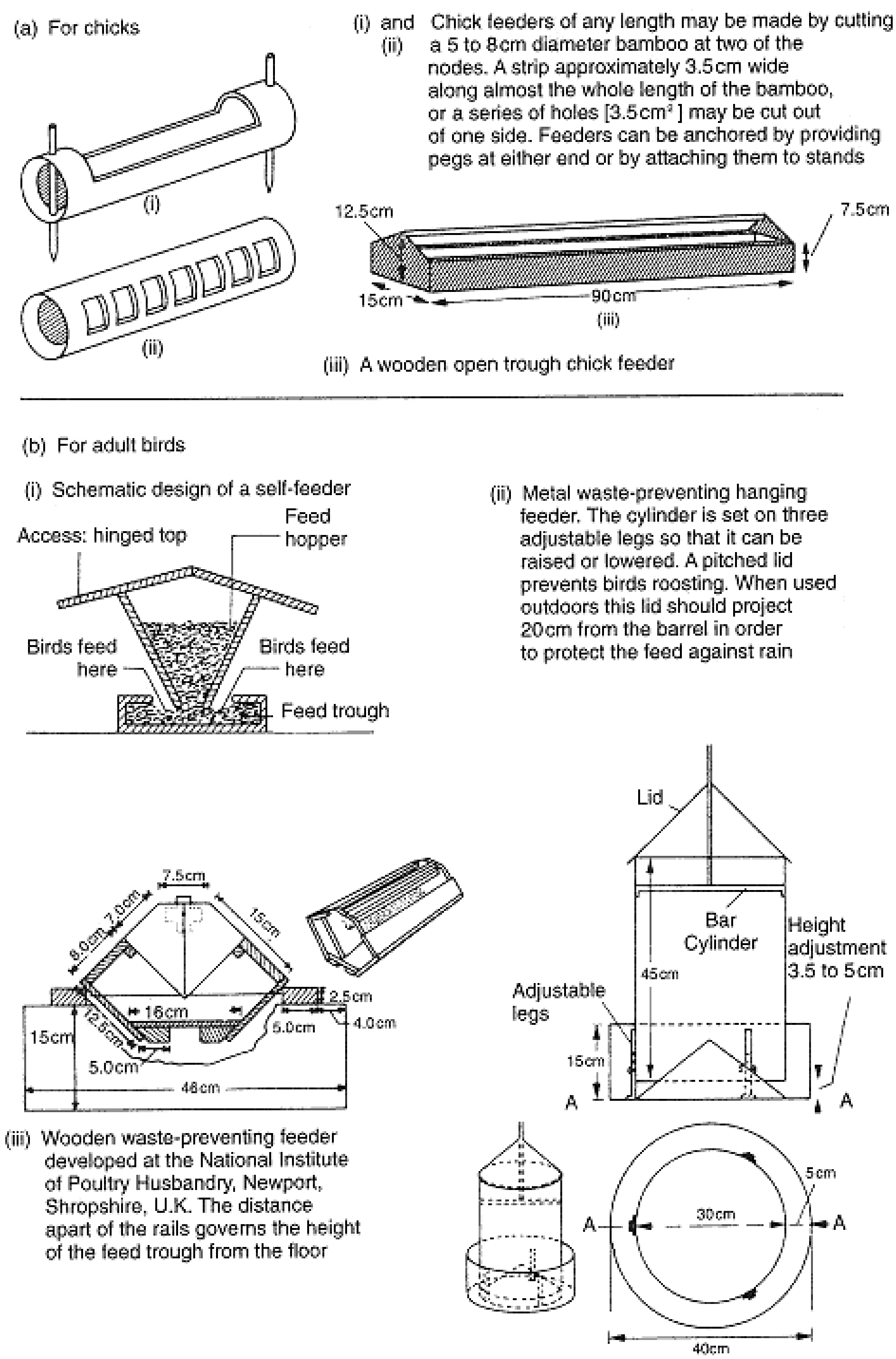

Fig. 15.6
Suitable, yet simple feeding and watering equipment.

Table 15.11 Number and distribution of ducks and turkeys in 1994.
(*Source:* FAO, 1995.)

Continent/ country	No. in 1994 (million)		AS % of world total	
	Ducks	Turkeys	Ducks	Turkeys
Africa	16	6	2.3	2.4
Ethiopia	8			
Madagascar	5	4		
Americas	28	111	4.1	44.9
Argentina	3	4		
Brazil	9	7		
Mexico	8	6		
United States	6	88		35.6
Asia	575	11	84.4	4.5
Bangladesh	15			
China	443		65.0	
Indonesia	27			
Malaysia	13			
Thailand	21			
Vietnam	30			
Europe[a]	41	85	6.0	34.4
Oceania	1	1	0.2	0.4
World	681	247		

a Continental totals do not equal the world total. This discrepancy is due to the fact that Russian Federation data is not included.

number of fowls (Table 15.1) and it could be assumed that it is the exacting nature of their climatic requirements that restricts their suitability for domestic use, together with the fact that they eat more feed than fowls and that some people do not find either their eggs or their meat quite as palatable as those of fowls. On the other hand, ducks lay more and larger eggs than most fowls, they grow to a greater size, they require little in the way of housing, they are not so susceptible to disease and parasites, they are better able to protect themselves from marauders and they are excellent foragers.

In all suitable regions, and in many that on account of the dryness of the climate would appear unsuitable, domestic ducks are kept by householders. In Southeast Asia, however, they are the sole source of livelihood of a considerable number of people who may own very large flocks. Commercial, large-scale duck-keeping has now expanded outside the Southeast Asian tropics to many other tropical regions (Warren, 1972).

Origin

With the exception of the Muscovy, all types of the domestic duck (*Anas platyrhynchos*) are considered to be derived from the green-headed mallard (*Anas platyrhynchos platyrhynchos*) of the family Anatidae. There are about 40 species of *Anas* with a chromosome number $2n = 78$. They are mainly monogamous and form pair bonds during the breeding season. Domestication is considered to have taken place in East or Southeast Asia, possibly at a number of different centres, at least 3000 and possibly 4500 years ago (Hetzel, 1986).

The Muscovy duck (*Cairina moschata*), a native of the Central and South American rain-

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forest, is also a member of the Anatidae family, but its chromosome number is 2*n* = 80 and crosses with domestic *Anas* ducks are sterile. It was possibly domesticated 9001000 years ago and several centres of domestication have been suggested; the Caribbean coast of South America (Crawford, 1990), the Chaco in Paraguay (Donkin, 1989) and the Peruvian Andes (Clayton, 1984). It was introduced into Europe by the Spanish conquistadores in the sixteenth century (Clayton, 1984). Muscovy ducks are distinguished by warty growths on their head, are polygamous in the wild and exhibit extreme sexual dimorphism, males weighing 3550% more than females.

Breeds and Their Productivity

There are a range of different types in a large number of duck breeds, some of which are bred in both temperate and tropical countries. In general, ducks in the temperate region are bred and used primarily for meat production, whilst in many tropical countries they are used as dual-purpose meat and egg producers. In Southeast Asia, however, they are managed primarily for egg production, under varied systems of management.

Major breeds used for intensive meat production in the tropics include the *White Pekin*, the *Aylesbury*, the *Rouen* and the *Muscovy*.

White Pekin

A white-feathered, slightly yellow-fleshed duck, weighing up to 4 kg when mature, that originated in north-central China. A fairly good layer (100150 eggs per year), under subsistence conditions this duck produces table birds weighing up to 2.7 kg. With improved management it will produce 2.53.5 kg ducklings at 7 to 8 weeks of age.

Aylesbury

A white-feathered, white-skinned, British breed that weighs 4.04.5 kg when mature and lays 80100 eggs per year. Used, particularly in the United States for crossbreeding with White Pekin ducks.

Rouen.

The largest of the major breeds with the feather colours of the wild mallard. It originated in France, grows rather slowly with mature birds weighing up to 5 kg and is not as fertile as some other breeds.

Muscovy

Apart from body size, hardly differs from its ancestors. It does, however, differ from other ducks. Eggs hatch in 35 not 28 days and hybrids with other duck breeds are infertile. It does not grow as rapidly as the White Pekin and the Aylesbury but will produce birds weighing up to 2.7 kg under subsistence conditions and lays 4050 eggs each year. It is very hardy and a good forager (Fig. 15.7). Muscovy are used in Southeast Asia and elsewhere either as pure-breds or for crossing with local breeds to produce infertile meat-type crossbreds. In Thailand the crossbred is known as *Poey Chai*, whilst in Taiwan a sterile but highly prized meat-type duck, known as the *Mule*, is produced as the result of the following second cross:

Other breeds of some importance, particularly in Asia, are:

Khaki Campbell (United Kingdom)

It is considered to have been developed from cross-breeding between the Indian Runner imported from Southeast Asia, the Rouen imported from

Fig. 15.7
Young Muscovy ducks in Ecuador.

France and the British wild duck. The mean adult liveweight is about 1.5 kg, it is a good forager and under subsistence management in the tropics produces 180200 eggs per year. Whilst under good management, Warren (1972) has reported that even when scavenging for part of its food, it can lay 300 eggs a year.

Indian Runner (Southeast Asia)

A white feathered duck with orange to reddish feet that originates from Malaysia and/or Indonesia. Mature, it weighs 1.52.0 kg and produces 150200 eggs per year.

Sythetmete and Nageswari (India)

These are duck breeds with only slightly different characteristics that produce 80150 eggs per year.

Paknam/Cholburi and Nanhoenpathon (Thailand)

Country breeds that are excellent foragers, weigh 1.01.5 kg when mature and produce 150200 eggs per year. They are often crossed with Khaki Campbell to produce ducks that weigh 1.8 kg and lay 250280 eggs per year.

Itik (Philippines)

There are other local names, but '*itik*' is the *tagalog* word for the mallard type of duck, used to provide eggs for the '*balut*' trade. The ducks are managed in flocks of 50100 head, mainly around the inland lake of Laguna de Bay on the island of Luzon, and are fed to a large extent on snails, molluscs and small fish. They weigh on average 1.5 kg and lay 170185 eggs per year. *Balut* is a Philippine delicacy; duck eggs are incubated for 1718 days and then boiled to kill the developing duckling. They are salted and eaten from the shell. Infertile eggs are boiled and marketed as a cheaper and inferior snack, known as '*penoy*'.

Itik Jawa (Malaysia)

A duck with a mature weight of 1.8 kg that produces 6080 eggs per annum.

Alabio, Bali and Tegal (Indonesia)

Under subsistence conditions these breeds provide ducks that weigh 1.8 kg and produce 6080 60 g eggs per year. Under improved conditions, however, Kingston *et al*. (1979) reported that the Alabio, a very uniform breed from south Kalimantan, can produce on average 245 eggs per year.

Tsaiya (Taiwan).

A duck that weighs 1.2 kg at maturity, commences laying at 45 months of age and produces 260290 eggs per year.

Breeding and Incubation

The usual number of ducks allowed to one drake is six, but if fertile eggs are the main consideration the number should be no more than four. Drakes should be placed with the ducks at least 1 month before fertile eggs are required. The belief that effective copulation can only take place in water is mistaken, although it is desirable that ducks should have access to water on which to swim. With water available they are able to keep themselves clean and nesting ducks are better able to keep their eggs at the correct humidity.

The Muscovy will interbreed with other types of duck, but as stated previously, the offspring are sterile. Other breeds of ducks are interfertile and will produce fertile crossbreds when mated with wild species such as the *Pintail* and the *Shoveller*.

Ducks normally begin to lay at about 6 months of age, although a breed such as the Khaki Campbell comes into lay 6 weeks earlier. Ducks of the improved laying breeds are, for all practical purposes, non-broody, as are the Java ducks of Southeast Asia. Even ducks of the White Pekin type cannot be relied on to incubate their eggs. Under these circumstances it is necessary to use broody hens or an incubator.

The incubation period is 4 weeks for all breeds except the Muscovy, for which it is 5 weeks. Muscovy ducks, though poor brooders, can incubate their own eggs and are capable of hatching up to 30, but it is usual for other breeds to hatch 1520. Hens will incubate duck eggs satisfactorily if the eggs are dampened at least once a day. They can hatch a maximum of 12.

If ducks are artificially incubated the temperature should be 0.6°C lower than that needed for hens' eggs and the relative humidity should never be allowed to fall below 60%. During the first 24 hours of incubation it is advantageous that the relative humidity should be 70%, and from the second to the fourteenth day the eggs should be turned twice daily and sprinkled with tepid water at least once a day. After the fourteenth day the eggs should be turned at least three times daily and sprinkled with water. Traditional incubation techniques, described for hen eggs earlier, are also used for duck eggs throughout Southeast Asia. Satisfactory hatching percentages of 7080% are achieved. After hatching it is simpler to sex ducklings than it is chickens.

Management after Hatching

Rearing

Ducklings hatched in the incubator should be transferred to a brooder as soon as they have dried. The 'cold' type of brooder is perfectly satisfactory in a tropical climate, but if for some reason it is necessary to use artificial heat, temperatures of 30°C during the first few nights gradually declining to 18°C within 14 days are satisfactory. Ducklings are generally remarkably active and should be allowed ample open space during the daytime. If ducklings have been incubated naturally they will thrive best if they are left with the mother for 2 or 3 weeks.

Choice of System

Any method of management applicable to fowls can be used for ducks. Managerial methods used in Southeast Asia are of particular interest and possibly could be used elsewhere.

In marsh, seasonally flooded and rice-growing areas thousands of ducklings are hatched by the traditional Asian artificial incubation system described elsewhere. The ducklings are sexed and the young stock are divided at an early age into flocks of males and females. When sufficiently grown they are herded over the marshes or freshly cultivated paddy fields and live on forage, small fish and crustaceans, etc., gleaned from the fields. When the birds are fully grown, all except breeding stock are sold to traders who herd them towards the large towns and cities, selling eggs and stock *en route*. These ducks may take up to 6 months to reach their market, walking several hundred kilometres. Selection within this system of management is probably the explanation for the walking ability of such breeds as the Indian Runner. Smaller flocks are also kept by local farmers under similar conditions, and in almost all the rice-growing regions of Southeast Asia herders may be seen directing their duck flocks using characteristic long wands.

Another managerial method of interest is the association of duck production with fish farming. Duck houses, particularly laying houses, can be built on dykes between ponds or over them. The latter is preferable, but more expensive. It is estimated that if the duck house is built over the pond 3035% of the nutrients in the duck feed are voided into the pond. This acts as a fertilizer, encouraging the growth of plankton that can be eaten by filter-feeding fish such as tilapia and carp, reducing the amount of pellet feed required by the fish by about 30%. The problems and possibilities of types of integrated system are discussed by Edwards (1986). Some appear particularly appropriate for smallholders in the wet tropics.

Where management of breeding stock on free range is not possible a semi-intensive system is the most desirable. Simple houses suffice for accommodation provided they are dry and cool. A suitable house should be situated on a dry foundation and may consist of upright poles supporting a thatch roof over a raised (15 cm) rammed earth floor enclosed by wire netting. Adult ducks require 0.28 m2 of floor space; those up to 7 weeks of age about half this area (Table 15.9). An outside run is desirable, and can with advantage include an area of swimming water, but this is not essential. Wire-netting or slatted floors can be provided and these assist in keeping the house clean and dry, but they are also not essential. Straw, hay or reed can be liberally strewn on the floor as an alternative. Nest boxes should be provided at ground level at the rate of one for every five ducks. Each should be approximately 40 cm in length, 35 cm in width and 30 cm high and any front retaining-board that may be used should be no higher than 15 cm. Ducks prefer to nest as close to the floor as possible.

All breeds of ducks lay either at night or early in the morning, usually before 09.00 hours, and those kept on open range are usually confined to their night quarters until the sun is well up and laying has been completed. If the open range is pasture the stocking rate should be no more than 43 ducks per ha.

Battery managerial methods can be modified for ducks and under special and specific circumstances may be profitable.

Health

Ducks appear to excel when compared to most other domestic poultry in their resistance to stress and in their tolerance of disease. Nevertheless, they suffer from a number of disorders, the more important of which are listed below.

Duck Virus Hepatitis (DVH)

Present in all tropical regions except Australia. Young ducks, 1 day to 4 weeks of age, are particularly susceptible. The disease is transmitted through contact and mortality is high. It can be controlled by vaccination of the breeding flock and/or the young ducklings.

Salmonellosis (Avian Paratyphoid)

Found in all tropical countries. Morbidity high and mortality can be as high as 10%. The disease can be controlled by good hygiene and the feeding of a medicated starter mash containing 0.011% furazolidone, from 1 day to 2 weeks of age (Table 15.7).

Duck Virus Enteritis (DVE or Duck Plague)

Ducks of all ages are susceptible, particularly the Muscovy. A vaccine is available.

Pasteurella anatipestifer (Duck Septicaemia).

One- to eight-week-old ducklings are very susceptible. The disease is controlled by the use of sulphamethazine in drinking water at a concentration of 0.200.25%.

Pasteurella multocida (Fowl Cholera)

Controlled by using a concentration of 0.044% chlortetra-cycline in the feed.

Internal parasites are numerous in ducks but they can generally be controlled by good management, though liver flukes may be a problem in some environments.

Ducks are particularly susceptible to, and intolerant of, mycotoxins in contaminated and mouldy feeds. They can also be subject to manganese and zinc deficiency symptoms when fed corn/soya bean rations. It is unlikely, however, that they will suffer from any of these conditions in the extensive systems under which they are managed in most tropical countries.

Feeding

Details of the nutrient requirements of meat-type and egg-laying ducks are provided by Dean (1986) and Shen (1986), respectively. These should be strictly adhered to by intensive duck producers with particular attention to the addition of 0.10.2% methionine and a minimum concentration of 25 ppm manganese and 30 ppm zinc in corn/soya bean rations. In this text, however, information is primarily provided for semi-intensive and extensive tropical duck producers.

Ducklings should be fed at least four times a day until they are 2 weeks old, and three times a day for a further 2 weeks. After this the number of feeds can be gradually reduced if they are extensively managed, and as the birds' foraging power develops. Three feeds a day are essential for ducks raised in confinement until they are 8 weeks old, but thereafter two feeds a day are sufficient. Pelleted feed is very suitable for ducks.

Feeds recommended for chicks are suitable for ducklings. Day-old ducklings should be given coarse milled cereals moistened with milk or water as the first feed and then a proprietary mash or one with a composition approximating to the following:

Milled cereal	35 parts
Fine cereal bran	30 parts
Fish or meat meal	20 parts
Extracted oil-cake meal	10 parts
Fine grit and minerals	5 parts

The mash should be dampened just sufficiently to make it 'crumble'. If it is too wet much of it is lost through the sieving process to which it is subjected in the duck's bill. Feeding should always take place in flat-bottomed, shallow troughs. The feeding space required by 100 ducklings is 7.3 m and 12 m for birds up to 3 weeks old and older birds, respectively (Table 15.4). Small discarded rubber tyres cut through the centre of the tread are very suitable for use as feeding troughs. No more feed than can be eaten in about 10 minutes should be fed at any one time. Grit or sand should be available *ad libitum*.

Adult ducks normally consume 170230 g of feed per day, but some adult ducks in full lay can consume as much as 280 g. Feeds recommended for fowls are generally suitable for ducks, but proprietary duck mashes are recommended for feeding semi-intensively managed birds. In regions where ample supplies of fresh fish and fish or shrimp meal are available the College of Agriculture of the University of the Philippines recommends the following ration:

Rice bran	60 parts
Maize meal	20 parts
Fish or shrimp meal or the equivalent in fresh trash fish	20 parts

To this is added 2% cod-liver oil and 2% oyster-shell with additional green feed if the birds are continuously housed.

Under semi-intensive managerial conditions more use may be made of local feeds. One-third of the meal ration may be replaced by cheaper vegetable feeds, household scraps and fodders such as sweet potato tops and water plants such as *kangkong* (*Ipomoea aquatica*).

Ducks on free range obtain their protein needs by foraging for small fish, crustaceans and insects so that their evening feed should consist of cereals, cereal brans and carbohydrate feeds such as cassava, sago, sweet potato, yam or taro.

A plentiful supply of clean drinking water should always be available adjacent to feeding troughs. Ducks constantly wash their bills in water, spilling the water all around them, so that under intensive conditions the water supply should be placed on a wire-covered platform to minimize any undesirable effects resulting from this constant spillage.

Geese

The goose appears to have been a more important domestic bird in ancient civilizations than it is today. Not only were geese a source of meat, fat, eggs and feathers, as they still are today, but they were kept for a variety of ritualistic purposes. They also possess other useful attributes. Their reproductive life is longer than that of any other domestic poultry. They are grazers, feeding on grasses, legumes and weeds, and are therefore efficient controllers of weeds in cultivated crops such as coffee, cocoa, bananas and pineapple. Geese also demonstrate some potential for controlling aquatic weeds such as water hyacinth (*Eichhornia crassipes*). Therefore they can be reared most economically in an environment where a supply of young, succulent fodder is always available, such as regions of high and continuous rainfall or marsh lands. They are also useful guards, their strident voices sounding the alarm at the approach of strangers and/or predators.

Although certain wild species migrate to the tropics during the cool seasons of the year, no domestic breeds have been developed in the arid tropics and those evolved elsewhere do not easily adapt themselves either to arid conditions or to very high temperatures.

Origin

Geese appear to have been domesticated in two different regions from different wild species. European and some Western Asian and North African breeds have been derived from the graylag goose (*Anser anser*), whilst the ancestor of the East and Southeast Asian breeds appears to have been the swan goose (*Anser cygnoides*). Breeds in areas between these regions are possibly the result of hybridization of the two types (Crawford, 1984b). European settlers in North America started to domesticate the Canadian goose (*Branta canadensis*), but abandoned the attempt when domestic geese were imported from Eurasia.

Domestication in both regions possibly commenced more than 3000 years ago and, as geese are easily domesticated, it probably occurred at several different centres in each region.

Breeds and Their Productivity

Two common breeds of European origin, the *Toulouse* and the *Embden*, have been introduced in small number into tropical countries. The Toulouse, originating from the area around Toulouse, France, is almost identical with its wild ancestor in colour but it is of heavier build. Ganders weigh 1213 kg at maturity and geese 910 kg. The females lay 50+ eggs per season. The Embden is white in colour and matures quickly, ganders weighing 13 kg and geese 9 kg. Geese of this breed only lay 3040 eggs per season. A third European breed, the *Roman*, is somewhat smaller than the Toulouse and the Embden but the geese lay up to 100 eggs per season and commence laying at 6 months of age.

Chinese geese, of which there are two types, the brown and the white (Fig. 15.8) are found throughout the humid tropical areas of Southeast Asia. They are smaller than geese of European origin, ganders weighing 5.4 kg and geese 3.6 kg at maturity, and are distinguished by possessing a knob over the bill, a slight pouching of the throat and blue eyes. These geese lay 4050 eggs in one season.

The *Egyptian* breed is lighter than the Chinese, whilst the *African* breed is much heavier, weigh-

Fig. 15.8
Chinese gander, goose and goslings, China.

ing up to 11 kg. The African is a good table bird but it only lays about 20 eggs per season. The Egyptian is hardy, an active forager and is well suited to humid tropical environments.

Breeding

Geese may live for 20 years. They begin to lay at 1 year of age, but females should not be bred until they are at least 2 years old, while ganders are normally not used until they are 34 years of age. Breed size should determine the ratio of ganders to geese. For the larger breeds the ratio should be 1:2 or 1:3, whereas with the smaller breeds it can be 1:5. As geese often mate for life they do not like changes in mating arrangements and difficulties may be created if an additional female is added to the 'set' or if the gander is changed. Egg-laying in geese reaches a peak during the fourth and fifth years of life, but they continue to lay satisfactorily up to 10 years of age. Geese of good egg-laying strains of the Chinese breed may lay up to 60 eggs per annum, each weighing 1.101.40 kg, but nondescript village geese in Southeast Asia lay approximately only 20 eggs per annum. Birds of the heavier European breeds lay from 30 to 40 eggs during a season.

A goose will sit on and hatch 1015 of her own eggs, but as hens are more amenable to management than geese they are often used for hatching the eggs of high-laying strains of geese, when maximum egg production is of importance and artificial incubators are not used. Large hens should be selected and these can usually only cover a maximum of four eggs. The eggs must be turned each day and liberally sprinkled with water after the middle of the incubation period. The eggs of the lighter breeds hatch after 2830 days, while those of some of the heavier breeds may require up to 34 days before hatching takes place.

In forced-draught incubators a temperature of 37.2°C should be maintained, while without forced-draught a temperature of 38.639.2°C is required immediately above the eggs.

Humidity requirements are approximately the same as those for duck eggs, and goose eggs must be turned, aired and sprayed twice daily up to the twenty-eighth day.

Management after Hatching

Rearing

Goslings that are artificially hatched should be treated in the manner recommended for ducklings, although they are hardier, grow faster and require proportionately more food. Dry, clean accommodation is essential, but they rarely require additional heat immediately after hatching. Goslings hatched in the nest should be confined at night with their parents for 610 weeks.

Adult Birds.

Geese are not normally managed on a commercial scale in the tropics, being maintained in small domestic flocks and invariably allowed free range, entailing little trouble or expense. They require a dry, well-ventilated house, that can be simple and of inexpensive design, in which they can shelter from intense sunlight during the day and be enclosed at night. About 0.2 ha of free range is required per bird, as is an adequate water supply. Provision of a pond may improve fertility. If confined, geese require floor space of at least 0.4 m2 per bird and nest boxes: one per goose, with a floor space of 0.23 m2.

In the temperate zone intensely managed force-fed geese will gain up to 4.5 kg in 1 month, but this practice is virtually unknown in the tropics.

Geese, like ducks, produce feathers that are difficult to pluck. Under commercial conditions it is usual for the goose to be killed and the body then dipped in hot melted wax and allowed to cool; the feathers are then peeled off with the wax.

Health

Geese, like ducks, are hardy birds, particularly when managed under extensive conditions. They can suffer, however, from many of the same diseases and parasites as ducks: paratyphoid and avian influenza being of particular importance. Treatment should generally be in the manner prescribed for ducks. Geese often suffer from lameness, particularly prevalent in drier areas where the ground may be very hard and there is no access to open water.

Feeding

Day-old goslings should be fed coarsely milled cereals moistened with milk or water. After 2 days finely chopped, tender green forage can replace one-third of the cereals. For the first few days the goslings should be fed four or five times daily, but after 1 week three feeds per day will be sufficient. The amount of food provided should be as much as can be eaten by the bird in about 10 minutes. If succulent young pasture is available this will provide all the feed required once the birds are 3 or 4 weeks of age. If only inferior pasture is available a supplemental mash of chopped, green, succulent forage and cereal bran will be required.

Fresh drinking water should always be available. As with ducks, water in which to swim is desirable but not essential for good health and fertility.

If it is desired to fatten geese they should be confined in a cool, dry but rather dark house so that there is neither opportunity nor encouragement for them to exercise. They should be fed to appetite on inexpensive carbohydrate feeds, such as sweet potato, yam, taro, rice or maize for about 1 month.

Turkeys

Comparatively few turkeys are reared in tropical countries in Africa and Asia, although they are common in some countries in the Americas (Table 15.11), from where they originated. The lighter breeds do, however, thrive very well in the dry tropics when they are allowed to range and there is adequate shade and feed. Indeed, properly managed they can be reared quite successfully in all except the very wet regions of the tropics and there is an increasing interest in rearing them in all tropical countries.

Origin

The domestic turkey (*Meleagris gallopavo*) is derived from the American wild turkey of which there were seven subspecies in North and Central America (Howard & Moore, 1984). The bird was first domesticated by the Indians in pre-Columbian times, probably in Mexico, between 1300 and 2200 years ago. This domestication would have been of the Mexican wild turkey (*Meleagris gallopavo gallopavo*). The domestic turkey had already been introduced into some Caribbean islands by the sixteenth century, and noted by Columbus, was of considerable interest to Spanish explorers and conquistadores. It was introduced into Europe via Spain (15111512), becoming established in that country by 1530, and then introduced into France by 1538 and into England by 1641 (Schorger, 1966).

It is possible that the subspecies (*M.g. merriami*) was independently domesticated in the southwestern region of the United States before the time of European exploration and discovery (Crawford, 1990). It would appear, however, that these domesticates became extinct in the early years of the eighteenth century and never contributed to commercial turkey stock (Crawford, 1992).

Turkeys bred in Europe were derived primarily from the Mexican turkey (*M.g. gallopavo*), but other wild turkey subspecies from the southwest of North America may have contributed genes. In the latter part of the sixteenth and the early part of the seventeenth centuries European bred turkeys were imported into the British, French and Dutch colonies in North America; for example to Jamestown, Virginia in 1607, where they were interbred with the North American wild turkey (*M.g. silvestris*). The hybrid stock became known as the American Bronze and on account of its greater size and vigour rapidly replaced the original Mexican domesticate in both North America and Europe. Modern turkey breeds have all been derived from this hybrid.

Breeds

Today, almost all intensely managed turkeys are white feathered, broad breasted and three-way crossbreds. Their dams are first crosses and their sires purebred. They are produced using artificial insemination (AI) as there has been a decline in the reproductive ability of these intensively managed birds. There appears to be a negative correlation between improved growth rate/body size and reproductive characteristics.

Pure breeds, such as the *Broad Breasted Bronze*, *White Holland*, *Narragansett*, *Black*, *Slate* and *Bonbon Red*, are still used to a limited extent in the United States and elsewhere, as well as for crossbreeding.

Bred for intensive production the modern turkey is an inappropriate bird for the small-scale tropical producer. It has leg problems, cannot mate naturally and is dependent upon very high standards of feeding and management. There are, however, unnamed '*criollo*' breeds of turkey, particularly in Mexico, that thrive under village conditions. They retain coloured feathers, possess narrow breasts, do not need artificial insemination to reproduce and only require limited attention under free-range conditions. The National Research Council (1991b) has suggested that there is an urgent need to conserve genetic variability in the turkey and to encourage the use of American criollo breeds throughout the tropics.

Breeding

Turkeys may commence to breed when they are 1 year old or less, but they are not fully mature until they are 23 years of age. Hens of the improved breeds in temperate climates lay on the average up to 90 eggs per year, but there is very considerable variation in individual egg-laying capabilities. The average weight of an egg is 85 g. Hens of the nondescript type of turkey usually reared in tropical countries may only lay 20 eggs per year with an average weight of 57 g.

Under free-range conditions it is usual to allow one *stagg* or cock turkey to mate with up to 10 hens. Staggs tend to be selective in their

mating, but one effective copulation suffices to fertilize a whole clutch of eggs and this is required only every 3 weeks or so. The size of the male can be so disproportionate that hens may be damaged by him, especially if his spurs are long and sharp.

Turkeys prefer to make their own nest, but they can be induced to lay where it is most convenient by the provision of roomy, well-protected nests. A suitable mating shelter for birds on range is a wigwam type, consisting of three poles covered on two sides by thatch, matting or sacks.

The incubation period is 2528 days. Although turkey hens in the tropics are often quite good brooders it is generally more satisfactory to set turkey eggs under fowls if natural incubation is required. When artificial incubation of eggs is employed the general managerial methods advised for fowls can be adopted, but special attention has to be given to the humidity of the incubator. The relative humidity should be 63% at dry-bulb temperatures of 37.2°C and after the twenty-fourth day it should be 7079% at a dry-bulb temperature of 36.1°C. In forced-draught incubators the temperature should be kept at 37.5°C until the twenty-fourth day and then lowered to 36.1°C. In incubators with no assisted ventilation a temperature of 38.9°C should be maintained above the eggs. There should be no turning of eggs during the first day of incubation or after the twenty-fourth day.

Management after Hatching

Brooding

Methods suitable for chicks are suitable for turkey poults, but the latter, when very young, are more susceptible to climatic stress. They are particularly stressed by cold, humid conditions. Ambient temperature on the first day of brooding should be 35°C and at the end of the first week 37.8°C. Thereafter the temperature should be lowered by 0.6°C each day until the normal ambient temperature is reached.

Within the warmed space in the brooder each poult requires a 80 cm2 area during the first week.

Rearing.

Turkeys can be reared in the same way as fowls. At approximately 16 weeks of age turkeys destined for breeding should be separated and fed on a different, higher fibre ration than turkeys destined for meat production.

Breeding turkeys can be reared on open range, in semi-confinement or intensively. Under range conditions the stocking rate can be 375 birds per ha. The methods used are approximately the same as those used for fowls, but more feeding and watering space must be provided (Tables 15.4 and 15.5).

Feeding

Turkeys have a strong aversion to any change in their feeding routine or in the nature of their food. When poults are transferred to the brooder it may be necessary to dip their beaks into both the feed and the water as they sometimes appear to have no desire to eat and they will either die or be very slow in their initial growth. At 1 day old they should be offered small quantities of fine mash, dampened by milk when it is available, or they should be given finely broken grain. Well-chopped, tender green feed should also be offered to them.

Rations for fowls can be used for turkeys if the CP content is raised by the addition of a protein-rich concentrate such as fish meal. Poults up to 10 weeks of age require a ration containing approximately 23% CP. The CP content of the ration should be gradually reduced to about 15% for mature birds. As stated in a previous paragraph, at 16 weeks of age turkeys destined for breeding are fed a ration containing a higher CF content.

The average feed intakes of light and heavy breeds are 120 g and 280 g per day, respectively. Supplies of fresh, clean water, green feed and flint grit should always be available for all except range-fed stock. Green feed need not be fed to the latter.

Health

Young turkeys are very susceptible to parasitic infection as well as to most of the diseases suffered by other poultry. Two diseases particularly prevalent in turkeys are blackhead and erysipelas.

Blackhead

This is a devastating disease of 8- to 16-week-old poults caused by the protozoa *Histomonas meleagridis*. The disease is transmitted by droppings and for this reason poults can best be managed on a wire or slatted floor. The common symptoms are droopiness, sulphur-coloured droppings and a dark head. Treatment is by administration of a suitable drug in the water or the feed. A veterinarian should be consulted for details and the dosage of suitable drugs.

Erysipelas

This disease is caused by the bacterium *Erysipelothrix insidiosia* and infection is usually from contaminated soil. It also affects sheep and pigs. The symptoms are a sudden loss of poults that are discoloured in the face. The disease can be treated by the use of antibiotics and, if it is very prevalent, veterinary advice should be sought as to whether a preventive vaccination programme should be initiated. Turkeys should not be allowed on range grazed by sheep and pigs.

Peafowl

Two species have been domesticated. The Indian peafowl (*Pavo cristatus*), extant in the Indian sub-continent and Sri Lanka, and domesticated for at least 3000 years and the green peafowl (*Pavo muticus*), of which three subspecies are found in Southeast Asia. Both species were probably domesticated for religious, aesthetic and economic reasons. Peafowl are of special interest or sacred in the Buddhist and Hindu religions and they have been used as a table bird, at least since Greek and Roman times and are still being raised for meat in Vietnam. In Europe, turkeys replaced peafowl as a table bird in the fifteenth and sixteenth centuries. Today peafowl are mainly kept for their ornamental value.

Peafowl are not fully developed until 3 years of age, when the male in full display has spectacular plummage. They are omnivorous, eating grass, herbs, fruit, seeds, insects and small reptiles and animals. Peafowl are polygamous, nest on the ground, lay four to eight eggs and incubate them for 28 days. Further information on the biology of peafowl is provided by Grahame (1984).

The green peafowl (*Pavo muticus*) is considered to be a threatened species.

Japanese Quail

A number of different subspecies of quail (*Coturnix coturnix*) are found in northern regions of Europe and Asia, North Africa, the Canary and Cape Verde Islands in the Atlantic, Central and Southeast Africa and the islands of the Comoros, Madagascar and Mauritius in the Indian Ocean. To date, however, only the Japanese subspecies (*Coturnix coturnix japonica*) has been domesticated and exploited on any scale.

The Japanese quail was originally valued as a song-bird and was probably domesticated *c*. 600 BP. It was not, however, until the first decade of the twentieth century that the song quail was bred for egg and meat production (Wagasugi, 1984). The industry grew rapidly in Japan and during the second part of the twentieth century in East and Southeast Asia, mainland Western Europe, the United States, Brazil and Chile.

Breeds and Their Productivity

Only the Japanese quail has been domesticated to date, but crossbreds with other wild quail subspecies are fertile. In Malaysia, using artificial insemination, local cockerels have been crossed with Japanese quail to produce a fertile hybrid known as the '*yamyuh*'.

Japanese quail hens lay up to 80 eggs under controlled lighting and are capable of producing 200300 eggs a year. However, at this rate of lay second-year egg production is normally half that of the first year and fertility and hatchability are reduced. Thus the commercial life of the bird is about 1 year. Eggs are normally mottled brown in colour but a white egg-laying strain has been developed by selection.

Individual eggs weigh 712 g or 78% of the hen quail's body weight. The incubation period is 1718 days and the chicks weigh 58 g at birth and are sexually mature within 4250 days. At this age the males, smaller than the females, weigh 90130 g and the females 110160 g. Meat strains have been developed in which the females weigh as much as 500 g.

Management

Quails have no homing instinct and cannot be used as free-range scavengers. They must be enclosed in pens with wire floors as male quail secrete a sticky foam from a gland located at the upper end of their vent. This foam mixes with their faeces and adheres to their feet when they are managed on conventional floors, presenting problems. The sex ratio should be one male to six females and the space requirement for mating pens is 160 cm2 per bird. About half this space allowance is required for laying females.

Domestic quail rarely go broody and do not usually incubate their eggs so that artificial incubation is almost essential. The temperature in the incubator should be 3135°C during the first week and be reduced to no less than 21°C by the end of the second week. In the tropics chicks can survive at normal room temperatures after the second week. Care should still be taken to avoid draughts and clean water should be provided at all times.

Health.

Japanese quail do not suffer from Newcastle disease but they do catch 'quail disease' an ulcerative enteritis that is controlled by antibiotics. Otherwise they are vulnerable to most of the diseases and parasites that attack other domestic birds, including blackhead, cholera and salmonella.

Feeding

Quail chicks require a concentrated high protein diet (27% CP and 2800 kcal ME/kg containing at least 1.1% lysine) up to 3 weeks of age. Between 4 and 5 weeks the CP percentage can be reduced to 24. After 5 weeks the chicks require a diet with 22% CP and 2900 kcal ME/kg. At all ages quail chicks have a high vitamin A requirement.

Guinea Fowl

Guinea-fowl are indigenous to savanna regions of Africa. There is disagreement, however, as to the origin of the domestic bird. Belshaw (1985) stated that *Numida meleagris* is descended from one subspecies of the seven known species of the family Numididae, whereas Mongin & Plouzeau (1984) concluded that there are two domestic species, *Numida meleagris* indigenous to West Africa and *Numida ptilorhynea* from East Africa.

The bird was probably domesticated at least 4500 years ago as guinea fowl appear on murals in the pyramid of Wenis at Saqqara, Egypt, *c*. 4400 BP. A thousand years later records in Egypt refer to the use of incubators constructed of mud bricks and heated by camel dung fires, for hatching guinea fowl and jungle fowl eggs (Belshaw, 1985). Domesticated guinea fowl were probably introduced into Southern Europe and Western Asia from Egypt. The domestic bird was known in Greece *c*. 2400 BP, its zoological name now being based on its Greek name. Two varieties were bred by the Romans, who considered both eggs and flesh delicious and acknowledged the bird's African origin (Belshaw, 1985).

For unknown reasons the guinea fowl disappeared from Europe sometime before the fifteenth century, at which time it was reintroduced by the Portuguese from West Africa. They also introduced the bird to India, Malaya and probably to Indonesia, while the Spanish who acquired it from the Portuguese, introduced it to the West Indies and the Americas. In many Asian and American countries the introduced semidomestic bird has reverted to the wild state.

At present wild and semi-domestic guinea fowl are extant throughout the savanna regions of Africa (Fig. 15.9). Ayeni (1983) estimated that in Nigeria alone there were at least 43 million free-ranging, semi-domestic guinea fowl.

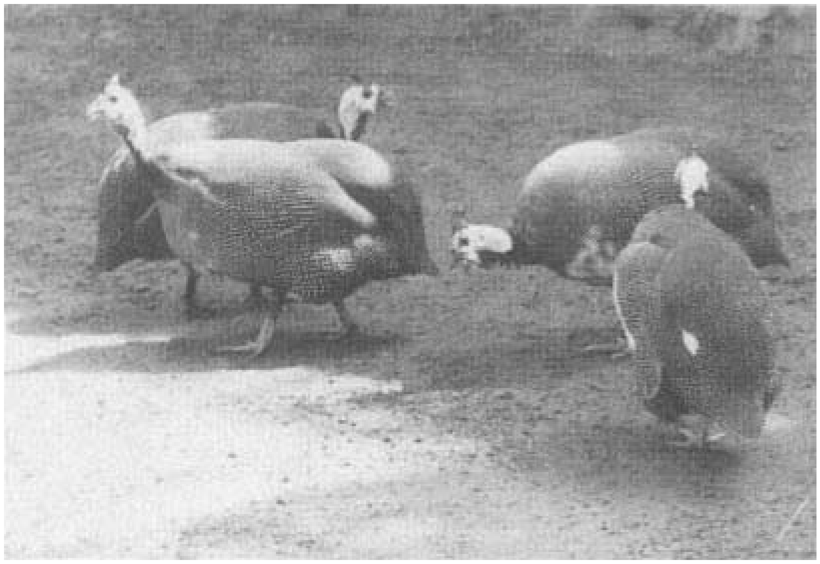

Fig. 15.9
Guinea fowl in Togo, West Africa.

Types and Their Productivity

There are four different colour types of the West African bird that was introduced into Europe in the fifteenth century: pearl, white, royal purple and lavender, pearl plumage being the most common. The latter is purplish-grey dotted or 'pearled' with white. Under free-range conditions in West Africa the female lays a clutch of 1520 brown coloured eggs. Under semi-intensive management the birds will lay up to 60 eggs in a season that usually coincides with the wet period. Under intensive management in Europe, mainly in France, Hungary, Italy and Russia, guinea fowl will lay up to 200 eggs a year, each weighing about 40 g. Adult birds weigh about 2.5 kg and the meat has a flavour like that of pheasant meat.

Management

The guinea fowl is a nervous but adaptable bird that forages well and is distinguished by its harsh cry. In West Africa it is usually managed as a scavenger around the house compound during the day, roosting on a high branch of a tree at night. Males are monogamous and the birds bond in pairs. Under intensive management, however, a male may be confined with up to four or five females. Females start to lay at 18 weeks of age but they will not come into lay if the ambient temperature falls below 15°C. The female goes broody after laying, but is a poor mother. Under semi-intensive and intensive management eggs are artificially incubated, the incubation period being 2627 days. Under semi-intensive management the chicks are penned until they are 12 weeks of age, they can be sexed at 8 weeks. Under intensive management in Europe guinea fowl are managed entirely indoors.

Feeding

Guinea fowl are omnivorous eating vegetation, seeds, insects, cattle ticks, termites, etc. In West Africa adult birds are expected to scavenge for feed but will be offered daily, small quantities of grain to retain them around the homestead. After hatching, chicks in northern Ghana are fed, for some weeks, termites supplemented with sorghum or millet grain. In order to trap termites, Ghanian farmers mix straw, cow dung and water in a pot, dig a small hole in a termite mound and then place the upturned pot over the hole.

Under intensive management the birds are fed concentrate feeds, but compared with chickens their food conversion rates are poor (3.03.6: 1.0) at best for meat production and guinea fowl grow comparatively slowly. Broiler chickens are slaughtered at 78 weeks of age whilst guinea fowl are slaughtered at 1214 weeks. The dressing percentage is 74% (Seet & Ahmed, 1994).

Health

Guinea fowl suffer from most of the diseases and parasites that afflict other birds, but they are more resistant to Newcastle disease, fowlpox and many common parasites than are chickens. The most prevalent and serious diseases are salmonellosis, pullorum, staphylococcus infections and Marek's disease.

Ostrich

There are four subspecies of the ostrich (*Struthio camelus*) in Africa. A fifth subspecies from West-

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ern Asia was exterminated in the middle period of the twentieth century. Some, or all of these, may have been domesticated or semi-domesticated in the past. It is known that Egyptians and Romans rode ostriches and fattened them for the table (Siegfried, 1984). Whilst some 200 years ago ostrich feathers were one of the principal exports of Darfur (Western Sudan) and ostriches were kept by many families in this region until well into the twentieth century (Wilson, 1976). These ostriches appear to have been captured and/or bred in captivity. The domestication or semi-domestication of this bird may have been a very widespread practice in the past as the Burun, a pagan tribe inhabiting an area in the northeast of the Southern Region of Sudan, almost 2000 km from Darfur, also kept ostriches for the production of feathers, eggs and meat until about the 1920s.

Increasing use of ostrich feathers by the fashion industry and a decline in the number of wild birds prompted the Acclimatization Society of Paris in 1859 to sponsor the domestication of ostriches in Algeria and Senegal and their breeding in Europe. At about the same time attempts were made to domesticate ostriches in South Africa, Asia, Australia and North and South America.

Only in South Africa were these efforts successful. A form of domestication that might be described as the semi-controlled breeding of semi-tame birds being established; the first commercial farm operating *c*. 1860. The semi-domesticated ostrich population of South Africa reached a peak at 1 million birds *c*. 1914, after which numbers fell as the feather trade collapsed. Since then there has been a series of slumps and recovery in ostrich numbers. In 1992, according to Shanawany (1995) the total world population of ostriches in captivity was 150 000, 95% of them reared in South Africa, but the economic basis for the industry has changed. Ostrich are no longer reared solely for feathers, but also for meat, leather and eggs so that the world population of birds is slowly increasing. Recently, Namibia has emerged as potentially the second largest producer of ostriches, the first farms being established in the 1990s.

Adaptability

The ostrich is an adaptable bird that can be reared in temperate and tropical countries, but it is best adapted to hot dry environments. Under cold conditions the feathers insulate the body and the bird covers its thighs with its wings. Under hot conditions it possesses several physiological mechanisms that assist in the alleviation of heat stress. Its panting system is well developed for heat loss, while it can cool itself by flapping its wings to improve the circulation of air around the body. Possibly the most important mechanism is one that allows the internal body temperature to rise faster than the temperature in the blood supply of the head. The bird also possesses mechanisms that allow it to withstand considerable water deprivation.

Biology.

The wild ostrich is a bird of semi-arid, subtropical to tropical short-grass environments. It is incapable of flight but can run for a short time at a speed of 110 km per hour. The male, which can attain a height of 2.4 m, possesses black and white plumage, the female which is smaller has greyish brown feathers.

Males can be monogamous or polygamous. In the wild a cock mates with one or two hens and domesticated ostriches are kept in pairs or trios. Ostriches are seasonal breeders with a breeding period of 68 months that varies with altitude and latitude. In the northern hemisphere the breeding period is from March to August/September while in the southern hemisphere it is from July/August to March. In very arid areas the bird has to behave as an opportunist breeder. The female lays an egg every other day in a ground nest within a communal nesting area in clutches of 2024 eggs, stops laying for 10 days and then starts to lay another clutch. The eggs are white to yellow-white in colour and large, measuring 1719 × 1415 cm and weighing 1.51.9 kg.

Eggs are incubated for 4245 days, the female sitting on the eggs by day, the male by night. Under natural conditions incubation commences about 16 days after the first egg is laid. Creches are organized in one locality by one or more older birds for the chicks and juveniles. The birds are restrained in the creches until they are about 9 months old. At 2 years of age it is possible to distinguish the sex of the growing birds.

In the wild the growing ostriches mature sexually at 45 years of age but under semi-domestication they mature as much as 2 years earlier. Females mature earlier than males and may live for up to 40 years.

Productivity

Mature ostrich weigh 110160 kg, the female weighing less than the male. According to Shanawany (1995) one female will produce 40 offspring per year and in a 407-day period a total of 1800 kg of meat, 50.4 m2 of leather and 36 kg of feathers will be produced by the offspring. Under good management egg production is 80100 eggs per season, if the eggs are continually removed from the nest, so that Shanawany's estimate of 40 living chicks per year is possibly conservative.

Feather production is best in arid regions, the feathers being harvested at 68-month intervals. Ostriches reared for meat production are killed at approximately 407 days of age, the killing-out percentage being 50. According to Shanawany (1995) the meat is low in fat (1%) and in cholesterol (63 mg per 100 g meat, compared with 86 mg in beef). This meat has become a valuable and fashionable food in Europe and North America and the demand is being met, not in general by African countries but by the development of ostrich farming in temperate regions of Europe and North America. The ostrich hide is thick, durable and extremely soft, with a very attractive grain.

Feeding and Health

Ullrey & Allen (1996) suggested that the turkey is the best model from which to predict the nutritional requirements of the ostrich. They also suggested that in order to minimize leg abnormalities in chicks kept under intensive conditions it is helpful to restrict liveweight gain by reducing the protein and increasing the fibre content of the diet. It is also useful to provide additional calcium in the diet, possibly by allowing chicks *ad libitum* access to oyster shell.

Ostriches eat termites and these and other insects may be used in ostrich diets as a suitable source of protein.

Pigeons

Pigeons are adapted for life in the air or on land. They have thrived with the development of agriculture and become almost a self-domesticating species in which it is difficult to distinguish between domesticated and wild birds.

It is generally considered that there are two domesticated species, the rock pigeon (*Columba livia*) and the Barbary or ring dove (*Streptopelia visoria*). The chromosome numbers of these species are $2n = 80$ and $2n = 78$, respectively (Hawes, 1984). Wild ancestors of the rock pigeon are extant in the northern British Isles, Southern Europe, North Africa, Western Asia and the drier regions of the Indian peninsula. The domesticated rock pigeon is found in most countries and the feral rock pigeon in most urban communities. The ring dove is almost entirely a domesticated species, but there are feral ring doves, particularly in some American cities (Hawes, 1984).

Types

Apart from urban feral pigeons that are opportunist scavengers, domestic pigeons can be classified into three groups. The first includes those types used for *squab* or meat production. The second includes the *carrier* and *homing* types of pigeon that exploit the bird's unique homing instinct and are used for long distance pigeon racing and/or the carriage of messages from one base to another. The third group includes those types specially bred for show and exhibition purposes, such as tumblers, rollers, shakers, pouters, etc. In addition, throughout history, pigeons have been used as symbols of sexual love, brotherly love or peace, presumably on account of

their pair bonding, mating display and cooing tones.

Domestication

There has been some association of the pigeon with man since the beginnings of agriculture in Neolithic times. The earliest known depiction of pigeons by man (*c*. 6500 BP) are figurines found at Arpachiya, Iraq (Zeuner, 1963). According to Kligerman (1978) domestication occurred between 3500 and 2600 BP. Dovecote husbandry probably first developed in Western Asia after domestication and then spread to Africa and Europe. Dovecotes have been built of mud, wood, brick or stone. Any structure that provides relatively safe and dry nesting places for the birds and where the young can be gathered for meat before they fly away is satisfactory. These practices probably reached their zenith in Europe in the seventeenth and eighteenth centuries though they have continued in Western Asia. Although carrier pigeons had been used for a very long time, their use for racing purposes developed rapidly during the nineteenth century and probably peaked during the first half of the twentieth century. The use of pigeons for show varies with changes in fashion.

Biology and Productivity for Meat

Pigeons achieve sexual maturity at 120150 days of age when they weight 0.51.0 kg and the female lays her first egg. The birds lay two eggs in a clutch and approximately eight clutches a year. Wilson (1979) studying pigeon culture in Southern Darfur, Sudan, noted that on average the first eggs were laid at 132 days of age, 17 eggs were laid per annum in 8.5 clutches and that eggs weighed on average 17 g.

Eggs of the rock pigeon are incubated for 1719 days while those of the Barbary dove only require 1315 days. For the first 45 days after birth the young are fed 'crop milk' that has a high fat content and consists of epithelial cells from the crop lining. It is produced by a unique process only available to species within the Columbidae family. Release of crop milk is controlled by the hormone prolactin and 4 or 5 days after birth it is replaced by regurgitated food provided by both parents and available for a further 28 days.

Chicks are harvested as squabs before full feather development at 2130 days of age when they weigh 300350 g. Specialized types of pigeon are used and one pair should provide 1214 sqabs in a year.

The life of a pigeon is about 15 years. Reproductive efficiency declines after 5 years but females can lay and males produce semen up to about 11 years of age.

Management

Pigeons can be extensively reared in semi-arid tropical climates. They range widely for their food that includes seeds, fruit, herbage and small invertebrates. Dovecote management is ideal for free-ranging flight though it is possible to rear pigeons in close confinement. In order to develop a 'homing instinct' the birds should be confined to and fed in the dovecote for 710 days or their wing feathers should be clipped and they should be fed close to the dovecote, so that by the time that they refledge their 'homing instinct' has developed. Inside the dovecote should be nesting shelves, with a lip to prevent eggs rolling away; two for each bonded breeding pair.

Pigeons must be provided with fresh water in some form of trough as, unlike most birds, when drinking they insert their beaks into the water and suck it up in a continuous stream. They should also be provided with a supply of grit. Any feed grains provided must be dry and free of mould. Pigeons do not thrive on mush. The nutritional requirements of pigeons are of the same order as those of chickens so that confined pigeons must be supplied with the same types of feed. Orphan squabs can be fed with egg yolk to replace the 'crop milk'.

Health

In general pigeons suffer from the same parasites and diseases as chickens. Salmonella and/or paratyphoid is present in most flocks at a low

level of incidence and coccidiosis and trichomoniasis are often present. Pigeons need protection from intestinal worms, lice and predators such as rodents.

Megapodes (Brush Turkeys; Incubator Birds).

Megapodes (family Megapodiidae) are indigenous to some Indonesian islands, Australia, Papua New Guinea and some adjacent Pacific islands. They are not unlike turkeys with sturdy legs and short rounded wings. They are unique in that they possess temperature sensitive beaks and employ natural resources for incubation of their eggs.

They lay relatively large (75230 g) pink-coloured eggs, measuring up to 10 × 6 cm, in a variety of nesting sites that provide the eggs with optimal temperature and humidity for hatching. The nest is usually a large mound of sand mixed with sticks and rotting vegetation, but it may be a fissure in the rock or hot sand in geothermal areas. The female lays 1230 eggs per season and these hatch at regular intervals. The emerging hatchlings at first remain solitary and a large proportion do not survive (Jones *et al*., 1995).

In the large mounds, eggs are laid in separate holes that the birds fill with decomposing organic matter. The cocks, who are polygamous, guard the eggs from predators and help to regulate egg temperature, using their temperature sensitive beaks. The desired incubating temperature appears to be 32.7°C. If the eggs are too warm, the males remove sand and vegetation, if too cool they add to the rotting vegetation. In the Mount Tovarvar volcanic region of the island of New Britain (Papua New Guinea) megapodes dig in the hot sand until they locate an area at the correct incubating temperature. Eggs are then laid.

Traditionally indigenous people have protected the nesting sites and refrained from undue slaughter of megapodes, practising a form of egg ranching (Argeloo & Dekker, 1996). Programmes to develop and supply sustained supplies of Megapode eggs are now being propagated in Papua New Guinea (National Research Council, 1991a).

Marketing of Poultry

The storage and transport problems associated with the marketing of poultry meat are the same as those associated with other types of meat. In most tropical countries culls and specially fed meat birds produced on small farms are marketed while still alive (Fig. 15.10). Broilers are generally marketed in the same way as they are in temperate countries, i.e. as frozen carcases.

Egg marketing does, however, present some special difficulties for the small producer. One of the major causes of egg spoilage is the development of the embryo in the fertile egg during the hottest periods of the year. Although some tropical peoples do not object to consuming eggs that contain an embryo in an advanced stage of development, this is not the normal attitude. Most consumers consider that an egg that has been stored under hot conditions for 48 hours is inedible.

The easiest method of dealing with this problem is to exclude cockerels from the laying flocks. If this is not practicable then the development of the embryo can be stopped by immersing freshly collected eggs in water kept at 57°C for a 15-minute period. They can also be treated by freezing, by soaking in lime water for approximately 18 hours or by painting with a white mineral oil of high viscosity. If a cool room is available the palatability of untreated eggs can be prolonged by keeping them at an ambient temperature of 18°C.

In Southeast Asia eggs are preserved in many ways before marketing. Two common methods are salting and preservation in wood ashes, lime salt and tea leaves for 100 days to produce the so-called 'ancient egg'. In some areas of the Philippines the embryo in a fertile duck egg is allowed to develop until the eighteenth day or later to produce a local delicacy known as *balut* (see earlier, p. 650).

Under normal conditions eggs do not lose much weight during storage at moderate ambient temperatures. In the dry tropics, however, at

Fig. 15.10
The use of a bicycle for transporting live poultry to market in southeast Sumatra, Indonesia.

ambient temperatures above 32°C and when humidity is low, the loss in weight during a short storage period may be more than 10%.

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16
Game

Introduction

Man exploits many species, other than those described in Chapters 7 to 15, for food and other purposes. We discuss the use of some of the more important of these species in this and Chapter 17. Inclusion of a species into one or other of the chapters is somewhat arbitrary. In this chapter we consider 'game' or wild species that were in the past hunted for sport, trophies or food but may now be semi-domesticated or conserved for food, tourism or aesthetic and cultural reasons. Whereas in Chapter 17 we discuss small species, designated as 'microlivestock' by Noel Vietmayer and his associates (National Research Council, 1991), that may be wild, semi-domesticated or domesticated.

Wildlife harvesting is amongst the oldest forms of human endeavour. Game was the main, if not the only, source of meat before man domesticated a limited number of species and hunting game has continued to be socially and economically important in many traditional societies until very recent times. Even today, game meat contributes substantially to the diet of some indigenous people in a number of tropical countries.

In the past, game had not generally been viewed as an irreplaceable resource in any specific location, with the consequence that as human populations expanded, game populations have been almost completely destroyed within large tracts of the tropical world. East, Central and South Africa have until now been the major exceptions to this trend.

Game reserves were created in some countries before the mid-twentieth century. It was not, however, until this period that conservationists in Africa realized that the creation of game reserves would not necessarily ensure that large numbers of game would survive on that continent. As man increases in number, he is bound to compete with other species and, in particular, with the wild species for land and water. Under these circumstances, unless substantial economic reasons can be advanced for the preservation of wild game, there will be no doubt as to the final issue. They will become extinct or, at best, survive in small number in national parks and zoos.

Reasons for the Preservation of Wild Game

At least four reasons may be advanced for the preservation of wild game: aesthetic, cultural, biological and economic. In the developing world the most important reason is the latter.

Wilderness areas stocked with wild game have an aesthetic value recognized by some, but not by all. Once the wilderness and the wild game have gone, they can never be exactly replaced.

Hunting is recognized by a majority of people as a comparatively harmless outlet for one of man's most powerful emotionsaggression. Without this outlet, man could be emotionally and culturally poorer and, as an increasing number of people live in the vast cities created by the new technology and economy, the need for some relatively harmless release for aggressive emotions will probably increase. Hunting can also provide a useful economic return in the form of licences and trophies.

Wild game are of intrinsic scientific interest and utility. They provide a gene pool which may yet be needed and some present wild species may yet be domesticated.

The economic value of wild game has hardly been assessed as yet. They can be used to exploit those areas of the earth's surface which cannot be adequately exploited by existing domestic livestock. As it would appear that many game animals are physiologically geared to a near-maintenance level of production, they can also survive in number in submarginal areas without destroying their habitat. They could not only be an additional source of meat but also of economically valuable skins, hair, bones and ivory. In addition, associations of large numbers of wild animals can become a major tourist attraction with consequent economic benefit.

Without in any way denigrating the aesthetic, cultural and biological value of wild animals or their use as an outlet for some of man's deep-seated atavistic tendencies, this chapter will focus attention on the utilization of wild animals as an economic asset.

Tropical Regions Where Game Could Be an Economic Asset

There are areas in many tropical countries where game animals could be cropped on a small scale. Even small schemes can be a valuable economic asset. More important, there are major regions in the tropics where game cropping could, if properly organized, become an industry which would produce considerable supplies of animal products.

Arid and Semi-Arid Regions

Approximately 31% of the world's total area has been classified as arid or semi-arid, of which about half is at present semi-arid. Some authorities consider that the semi-arid lands are expanding, particularly in Africa where about one-quarter of the total area is classified as semi-arid.

Of the domesticated livestock, only camels can thrive, year-round, in arid lands. Cattle, sheep and goats do, of course, utilize the ephemeral forage plants which appear after rain, but cannot be managed year-round on desert range. There are, however, a number of antelopes which are indigenous in the arid regions of Africa and Western Asia. These include: the major types of *Oryx* spp. such as the gemsbok and beisa oryx in Africa and the Arabian and scimitar oryxes in Western Asia; the addax (*Addax nasomaculatus*), which once ranged throughout North and Northeast Africa; and *Gazella* spp., such as Loder's gazelle found in the dune areas of the Sahara, Speke's gazelle found in Somalia and the goitred gazelle of Arabia. In addition, gazelle such as Thomson's (*G. thomsoni*) and Grant's (*G. granti*) inhabit the semi-arid regions of Africa.

The antelope population of the arid and semiarid areas of Africa and Western Asia has been radically reduced of recent times, but it can be envisaged that proper management of these zones could include sustained cropping of antelopes. Animals would have to be reintroduced in many areas. This has already been accomplished in Jordan and Oman (Price, 1986) by the reintroduction of the Arabian oryx (*Oryx leucoryx*).

In the semi-arid and some other areas of Australia it could be economic to crop kangaroos, especially where the climatic environment is unsuitable for domestic livestock. Sharman (1967) reported that kangaroos survive drought very well and make use of very poor roughage. They are better adapted to marginal land than sheep or cattle and apparently are quite efficient converters of feed into liveweight. The total number of kangaroos that could be involved in cropping schemes would not be inconsiderable as a survey in New South Wales showed that, in that state alone, in 1960 there were at least 10 million. Kangaroos are systematically culled, but national legislation forbids their killing under commercial conditions to provide human food. A proportion of the culled animals are, however, used to produce pet food.

Savanna and Steppe Regions

Harthoorn (1961) estimated that 10.4 million km2 of savanna and tropical steppe in Africa were infested with tsetse fly. The majority of livestock breeds cannot be utilized in this vast area on account of the danger of contracting trypanosomosis. Only two major breeds of cattle, the N'Dama and the West African Shorthorn, together with some remnant cattle breeds such as the Binga of Zimbabwe and a limited number of sheep and goat breeds, are tolerant of trypanosomosis. Many game animals are, however, tolerant. Until tsetse-infested land is closely settled, the cropping of game could be an important economic activity on such land. There is often a multiplicity of game species in such areas, similar to those listed later in Table 16.1, so that the opportunities for sustained cropping could be particularly favourable.

The *llanos* of Colombia and Venezuela in South America may be a very suitable region for mixed game and domestic livestock production. For example, the capybara (*Hydrocheorus hydrochaeris*) a rodent known as *el chiguire* in Venezuela, is very well adapted to the seasonally flooded *llano* environment and produces an acceptable meat. It is a herbivore, extant from Panama to Paraguay, possessing a very large caecum, that lives in shallow but not rapidly flowing water and feeds primarily on aquatic vegetation. Mature animals weigh 4060 kg and yield a 52% dressed carcase. Males and females are sexually mature at about 18 months of age when they weight approximately 30 kg. Females give birth to litters of two to six young at about 8-month intervals. It is estimated that the cropping rate could be 30% (Kyle, 1987). In Venezuela there is a considerable Eastertime trade in the meat of the *chiguire*. Further information on the capybara is provided in Chapter 17.

In Brazil the rhea (*Rhea americana*), a ground bird weighing up to 25 kg when mature, and the armadillo (*Dasypus novemcinctus*) found in the *cerrado* are both used as a food source and could be exploited within some system of semi-domestication.

In Australia the emu (*Dromaius novachollandie*), weighing up to 55 kg when mature, is a possible source of meat.

Humid Forest Regions.

It is likely that, despite intensive exploitation, at least 25% of the total land area of Southeast Asia, or 1.25 million km2, will remain as forest for the foreseeable future. This vast area could be used for sustained timber production and be restocked with wild game. At present, there are few game in the Southeast Asian forests, as they have been over-hunted, but these forests are the ancestral home of the *Bos (bibos)* spp. types of wild cattle and several species of deer. If immediate action were taken to conserve the existing herds of gaur (*B. (bibos) gaurus*) and banteng (*B. (bibos) banteng*), their number would eventually increase until, ultimately a hunting and/or cropping programme could be justified (Payne, 1968). Restocking could be hastened by the introduction of Bali cattle, a domesticated type of banteng, and by allowing introduced cattle to go feral in the forests. It has also been suggested (Vu Ngoc Tan, 1968) that the raising of indigenous deer such as the sambar (*Cervus unicolour*) and the hog deer (*Axis porcinus*) could be economically attractive. There is no reason why the forests should not ultimately be also restocked with these and other indigenous deer species.

A considerable part of the total area of forest land in Southeast Asia is swamp forest. Consideration should also be given to the possibilities of stocking suitable swamp forests with domesticated swamp buffalo and allowing them to go feral. This has occurred fortuitously in south Sumatra, Indonesia, with desirable results. During World War II buffaloes were driven into the swamp forest to escape confiscation by the invading armed forces. Today, the descendants of the original buffaloes are feral, thriving and increasing in number. They now provide a sustained off-take of animals from an area which would otherwise produce little of economic value. Buffaloes introduced into northern

Australia have also become feral and have been cropped.

In West Africa there is a rodent known as the grass cutter (*Thryonomys swinderianus*) whose meat is appreciated by many of the indigenous people. A study of the ecology and reproductive biology of this species is now being undertaken in the Côte d'Ivoire, together with an attempt to breed the animal in captivity. Further information on the grass cutter is provided in Chapter 17.

The largest area of humid rainforest in the world is to be found in the Amazon basin of South America. The game population of the region has been considerably reduced in number by the clearing of the forest and over-hunting, but there have been some attempts at semi-domestication. The tapir (*Tapir terrestis*) produces excellent meat and has been tamed, though not fully domesticated, by the Conibos Indians of Peruvian Amazonia. Also in some areas the indigenous peoples catch and keep in captivity peccaries (*Tayassu* spp.) but these animals have never been fully domesticated.

The cassowary (*Casuarius* spp.), a forest ground bird that, when mature, weights <85 kg and produces meat that is highly regarded by indigences in New Guinea, has not been domesticated. It is of some interest as the male is responsible for the nests of two females and the consequent care of the fledglings from both nests.

The ranching of butterflies, as practised in Papua New Guinea, could be conducted elsewhere. A typical butterfly ranch consists of a small area of cultivated plants that attract butterflies from the forest to feed and lay their eggs. The resulting caterpillars are collected as chrysalises from which the adult butterflies emerge in captivity (Hutton, 1985).

Montane Regions

The high mountain and *altiplano* areas of Venezuela, Colombia, Ecuador, Bolivia and Peru comprise a major region where the possibilities of sustained game cropping should be considered: not only the possibility of restockingwith indigenous wild llamoids, such as the guanaco (*Lama guanicoe*) and the vicuña (*Vicugna vicugna*), but also the possibility of introducing exotic game animals from the montane regions of Asia and elsewhere. A reserve for vicuña, Pampas Galeros, was established in the Peruvian *altiplano* in 1976. Further information on the llamoids is provided in Chapter 12.

During historically recent voyages of discovery and through migration, man has introduced exotic domesticated and wild plant species from one continent to another, and domestic species together with some wild animals from Europe to the remainder of the world, but he has not generally introduced exotic mammalian species from one region of the tropics to another. It is suggested that the problems of restocking regions denuded of game, particularly by the transfer of game animals from one region to another should now be studied on a global basis. There are obviously major difficulties to be overcome, such as the possibility of transmission of exotic disease and parasites and the unknown competitive effects of the introduction of a new species on all other species in the environment. With time, however, adequate research and the introduction of new technology such as embryo transfer, these problems could be solved.

An example of what can be achieved by the introduction of exotic species may be studied in the state of New Mexico in the United States. In the 1950s Barbary sheep (*Ammotragus lervia*) were released at several centres in the state and, in addition, there may have been a few of these sheep already present which had been introduced at some previous date. This species has acclimatized and reproduced so well that it may now be hunted for 9 days in each year. The possibilities of acclimatizing the gemsbok (*Oryx gazella*) and greater kudu (*Tragelaphus capensis*), the Siberian ibex (*Capra siberica*) and the Iranian ibex (*C. aegugrus*) have also been studied. The present indications are that the gemsbok and the Iranian ibex will acclimatize and be very suitable species. In November 1970, Iranian ibex were released on a 2225 m peak of the rugged Florida mountain range, some 24 km south of the small town of Deming, new Mexico, in the United States.

Inland and Estuarine Waters

The possibility of conserving and utilizing the manatee (Trichechidae) of the Atlantic and Caribbean and the dugong (Dugongidae) of the Indian Ocean for feeding on aquatic plants in tropical and subtropical estuarine areas should also be considered. These water mammals were in the past highly prized for their meat but they have been over-hunted and are now extinct in many countries.

Crocodiles, alligators and caymans are being farmed in several tropical and subtropical countries, but at least one million wild individuals are killed each year for their skins; drastically reducing wild populations. The extension of farming would assist in the conservation of the wild individuals.

A major advantage of farming crocodiles, alligators and caymans is their high food conversion rates of 2:1 in the first 2 years of life and 3:1 or 4:1 in the third year of life, when they are usually cropped for their skins. Major disadvantages are that they are difficult and sometimes dangerous to handle and that they require food with a high animal protein content. Some further details of crocodile farming are provided in Chapter 17.

The possibility of farming turtles, that can be fed on vegetable feeds, to produce meat, leather and shell, is certainly worth consideration. In at least two regions of the world, turtles are at present captured in the wild and kept in ponds to be used as a food reserve. In the South Pacific marine turtles are corralled in ponds adjacent to the ocean and fed vegetation until they are required for feasts. In the Amazon basin in South America, aboriginal peoples keep several types of turtle in ponds, to be used as a food reserve. *Podoenemis expansa*, the largest freshwater turtle, that may weight <50 kg and produce <7 kg of prime meat, is one species kept in this manner. This turtle lives for 30 years and produces 90 eggs per annum from the age of 8 years. As it is estimated that only one in 500 of the young survive to reproduce, there is obviously major scope for domestication or part-domestication of this species. Schemes to raise freshwater turtles in ponds in Brazil and the marine turtle (*Chelonia mydas*) in the Cayman Islands have however, had to be aborted in order for the countries concerned to comply with current CITES (Convention on International Trade in Endangered Species) regulations. There is obvious scope for a review as to how specific turtle species can be semi-domesticated without endangering the existence of those in the wild.

Methods of Using Wild Game

The possibilities of using wild game for the production of meat and other products in Africa have been widely canvassed and discussed during the last decades of the twentieth century. Major sources of information on this subject are publications by Dasmann (1964), Talbot *et al*. (1965), Ledger *et al*. (1967), Joubert (1968), Crawford (1968), Child (1970), Skinner (1973), McDowell *et al*. (1983), Fairall (1984), Luxmoore (1985), Swanson & Barbier (1992) and Eltringham (1994).

There are at least four major methods by which wild game could be utilized for the production of meat and other products. These are:

(1) Hunting wild game.

(2) The sustained cropping of indigenous wild or introduced exotic game populations in environments generally considered unsuitable for the economic management of domestic livestock.

(3) The management of wild or semi-domesticated game with or without domestic livestock on ranches or farms.

(4) The domestication of some existing wild species and their managementeither alone or together with traditional domesticated species.

Hunting Wild Game

Small-scale hunting economies have existed throughout the tropics for very long periods. An example in Africa would be the Glwi people

of the Kalahari whose annual consumption of game meat in the years 195866 was estimated to be 93 kg per capita (Marks, 1989). Details of subsistence hunting in the tropics are provided by Robinson & Redford (1991).

At the opposite extreme is big game hunting, a sport of the seriously rich that is rapidly becoming restricted to a limited number of countries that can convince the international conservation lobby that their wildlife can be managed rationally. It is particularly lucrative for regions that lack scenic attractions but in which there are still big game. The objectives of big game hunting are, of course, the 'kill' and the collection of trophies, not food. The major game targeted have been predators such as the lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonx jubatus*) and tiger (*Panthera tigris*) and large herbivores such as the African elephant (*Loxadonta africana*), *African* buffalo (*Syncerus caffer*) and the black rhinoceros (*Diceros bicornis*). For sport hunting, licences or permits are issued for the shooting of individual animals by the responsible government department. 'Safari' organizations then provide complete services, from obtaining clearances for arms and ammunition to the transport home of the clients together with their trophies.

In Zimbabwe a sophisticated system has been developed for the exploitation of all forms of hunting. An inner core area is used for big game safaris with a low take-off of trophy game. The hunting of plains game is allowed in the surrounding area where there are no domestic livestock. Outside this area ranch hunting is licensed where the density of domestic stock is less than 60 per km2. Clarke *et al*. (1986) claim that this system provides a better economic yield than extensive cattle ranching.

Sustained Cropping of Game Populations

Wild game must be present in sufficiently large number and be able to range over a sufficiently large area before game cropping should be considered as an economic activity. Ledger (1964a) estimated that an area of no less than 20 000 ha is required in one block to allow for the migratory habits of game. Even this area is too small for some antelopes and for the larger game animals. Small gazelles could, however, be cropped from smaller areas. This is the situation in South Africa where there are more than 8000 ranches (average size 2530 ha) on which some game cropping occurs.

Advantages

(1) Wild game can be cropped in regions where domestic livestock cannot be utilized or are marginally economic

For example, it can be envisaged that in many African countries game-cropping schemes could act as buffer zones between very dry or tsetse-infested regions and ranching areas. Game may also be culled (cropped) on an intermittent basis in national parks and game reserves during periods when the public is excluded.

Game animals exhibit numerous adaptive features which make them very suitable for use in the ecosystems in which they are found. This is particularly noticeable in semi-arid and arid areas where some game animals can thrive without continuous access to free water. There is, however, little evidence to suggest that they are able to make better use of the food that they consume than do domestic livestock. For example, Taylor & Lyman (1967) have shown that in the same environment the productivity of eland is inferior to that of Hereford cattle, a higher food consumption and more protein being required for each unit of meat produced.

(2) The high game biomass available for cropping where there is a multiplicity of animal and plant species

Lamprey (1964) reviewed the available data on wild game biomass and concluded that in East Africa it could vary from 219 to 20 484 kg/km2 depending on environmental and other conditions. The upper limit was exceptional and was calculated in an area where there were numbers of the largest game, such as elephants, hippopotami and buffaloes. Dasmann (1963) stated that in Zimbabwe game cropping was more profitable than domestic livestock production in those areas where the stocking rate for cattle is less than 1 livestock unit per 12 ha, i.e. the domestic livestock biomass is less than 3333 kg/km2. Mentis & Dake (1976) concluded, however, that the carrying capacity of the natural veld in Natal was no greater for game than it was for cattle.

The possible high biomass of game animals available for cropping in some environments can be attributed to the fact that the available forage can be most efficiently utilized by many different animal species, each with slightly different food preferences and feeding habits. This situation is well illustrated by the data given in Table 16.1, showing the recommended annual game crop for a ranch in Zimbabwe.

Estimates of the biomass of game animals should be accepted with caution as there are so many variable assumptions in the calculations. Nevertheless, the general thesis that in some ecosystems game can produce a very substantial biomass per unit area of land is generally acceptable.

The fact that a specific environment supports a high biomass of game animals does not necessarily mean that productivity per unit area of land will be high. If all the animals grow very slowly, then most of the available feed would have to be used for maintenance purposes and annual off-take could be low. High productivity per unit area of land depends on both a high biomass or stocking density and a high off-take. High biomass and off-take depend upon large quantities of feed being available for the animals on a year-round basis, on high reproductive and growth rates within the species involved and on low mortality rates. For example, if the off-take is 3% in a game-cropping area where the biomass is 20 484 kg/km2, whereas in a ranching area where the biomass is only 10 000 kg/km2 the off-take is 15%, then total productivity in the ranching area at 1500 kg of liveweight per km2 per annum would be more than twice that in the game-cropping area where productivity would be 615 kg of liveweight per km2 per annum.

The reproductive rates of some game animals (Table 16.2) can be quite high, while liveweights (Table 16.3) can be of the same order as those for indigenously managed domestic livestock in many tropical countries. Under these circum-

Table 16.1 Recommended game crop from 130 km2 of the Henderson Ranch, Zimbabwe. (*Source*: Dasmann & Mossman, 1961.)

Game species	Estimated population	Percentage crop	Carcase weigh (kg)	Total carcase yield (kg)
Impala	2100	25	29	15 479
Zebra	730	20	116	16 887
Steenbok	200	20	5	218
Warthog	170	50	32	2 699
Kudu	160	30	102	4 899
Wildebeest	160	20	118	3 774
Giraffe	90	17	454	6 804
Duiker	80	20	9	254
Waterbuck	35	30	91	635
Buffalo	30	17	259	1 293
Eland	10	20	272	544
Klipspringer	10	30	6	19
Bush pig	10	50	32	159
Total				53 664

Yield: kg/ha of game meat: 4.1.
kg/ha of beef after development: 3.4.

Table 16.2 Reproductive biology of some game animals.

Species	Sex	Type of breeding season	Age at first breeding (months)	Gestation length (days)	Interval between parturitions (days)	Births as percentage of breeding females	Source
Blesbok (*Damaliscus dorcas phillipsi*)	Male	Seasonal	18				Skinner, 1973
	Female	Seasonal	18	225	365	85	Skinner, 1973
Buffalo (*Syncerus caffer*)	Female	All year	57	n.a.	540730	5066	Grimsdell, 1973
Eland (*Taurotragus oryx*)	Female	All year, seasonal peaks	2631	268276	334374	83	Skinner, 1973
Impala (*Aepyceros melampus*)	Male	Seasonal	18				Skinner, 1973
	Female	Seasonal	18	196	365	90	Skinner, 1973
Kudu (*Strepsiceros strepsiceros*)	Female	Seasonal	17	210214	365	100	Skinner, 1973
Springbok (*Antidorcas marsupialis marsupialis*)	Male	All year	13				Skinner, 1973
	Female	All year	7	168	210	46100	Skinner, 1973
Thomson's gazelle (*Gazella thomsoni*)	Female	All year	517	170200	180	n.a.	Furley, 1986
Wildebeest (*Connochaetes taurinus albojubatus*)	Male	Seasonal	40				Estes, 1966
	Female	Seasonal	1527	240-255	365	96	Watson, 1969

n.a. = not available.

stances the off-take from a game population could compare quite favourably with the off-take from an indigenously managed domestic livestock population. Watson *et al*. (1969) estimated that the off-take of game animals under favourable conditions could be of the order of 10% per annum on a sustained yield basis. This is approximately the same off-take as would be achieved by an indigenous cattle herd, but much lower than the rate that would be achieved by a well-managed modern integrated livestock unit. It must also be recognized that many game animals do not live under favourable environmental conditions, indeed they are most often confined to areas where conditions are unfavourable.

(3) The relatively high fertility of some game species

As will be seen from Table 16.2, the calving percentages of the buffalo, eland and wildebeest compare favourably with those of indigenous cattle in similar environments, and the age at first breeding of both the eland and wildebeest is lower than is normal in indigenous cattle. It may be concluded that the reproductive efficiency of both the eland and the wildebeest is higher than that of most indigenous cattle.

The lambing percentages of smaller game animals such as the springbok, impala, blesbok and Thomson's gazelle are of the same order as those

Table 16.3 Mature liveweight of some African game animals.

Species	Mature liveweight (kg) Male	Female	Source
Blesbok (*Damaliscus dorcas phillipsi*)	72	63	du Plessis, 1972
Buffalo (*Syncerus caffer*)	688	531	Georgiadis, 1985
Eland (*Taurotragus oryx*)	533; 500a	362; 410	Georgiadis, 1985; Skinner, 1967
Impala (*Aepyceros melampus*)	50 (4065)	40; (4050)	Child, 1964; Nowak & Paradiso, 1983
Kudu (*Strepsiceros strepsiceros*)	100	88	Georgiadis, 1985
Oryx (*Oryx beisa*)	173 (133189)	149 (130163)	Ledger, 1963b
Springbok (*Antidorcas marsupialis marsupialis*)	34; 37	28; 25	Georgiadis, 1985; Skinner *et al*., 1971
Thomson's gazelle (*Gazella thomsoni*)	25; 25	21; 20	Georgiadis, 1985; Ledger, 1963b
Uganda kob (*Adenota kob*)	97 (88108)	62	Ledger, 1963b
Wildebeest (*Connochaetes taurinus albojubatus*)	253; 204 (186228)	187; 162 (150175)	Georgiadis, 1985; Ledger, 1964b

a Semi-domesticated animals in Zimbabawe.

of indigenous sheep, although they may be some-what lower than those of indigenous goats. In the case of the springbok, there is some evidence that cropping increases the lambing percentage (Van Zyl & Skinner, 1970). Removal of the young at a relatively early age apparently reduces the stress on the mothers due to lactation, and they come into oestrus sooner. It must be stressed that accurate comparisons of fertility rates are difficult on account of the importance of environmental interactions and particularly that of nutritional status.

(4) The relative tolerance of some game species to endemic disease and parasites

There is a tacit assumption in the major part of the game-cropping literature that the disease factor can largely be ignored in wild game. This is definitely not the case. Hammond & Branagan (1973) reviewed present knowledge of the disease spectrum in wild ruminant game in Africa and concluded that little is known as yet of the natural incidence of disease among these animals and even less of the epidemiology under ranching conditions. Young (1975) stated that game are continuously threatened by disease and parasites. These conclusions are reinforced by a study on a mixed game/domestic livestock ranch in Kenya (McDowell *et al*. 1983) where it was found that although carcase condemnations were low (<1%), the internal parasite burden of the game species was greater than that of the cattle with higher condemnations of offal.

Many African wild ruminants apparently possess a degree of trypanotolerance and thrive in large numbers in tsetse-infested regions where most domestic livestock cannot be managed. There appear to be no specific animal health reasons why advantage should not be taken of this situation by the introduction of sustained-yield game cropping.

(5) The high killing-out percentage and lean content of many game carcases

The killing-out percentage of most game species is relatively high (Table 16.4) and the carcases of African ungulates are characteristically very lean, containing only a fraction of the fat contained by the carcases of domestic ruminants. When game animals are properly slaughtered

Table 16.4 Carcase dressing percentage of some game animals.

Species	Sex	No. in sample	Liveweight (kg)	Carcase dressing percentage	Source
Blesbok (*Damaliscus dorcas phillipsi*)	Male		73.4	52.9	Huntley, 1971
Buffalo (*Syncerus caffer*)	n.a.			49.4	Young & Van Den Heever, 1969
	Male	8		50.5 ± 2.5	Ledger *et al*., 1967
Capybara (*Hydrochoerus hydrochoeris*)	n.a.			52	González-Jiménez & Parra, 1973
Eland (*Taurotragus oryx*)	Castrate		412.7	63.2	Von la Chevallerie *et al*., 1971
	Male		408.5	51.3	Von la Chevallerie *et al*., 1971
	Male			57.4	Keep, 1972
	Male	5		59.1 ± 3.6	Ledger *et al*., 1967
Gerenuk (*Litocranius walleri*)	Male	5		65.0 ± 2.1	Ledger *et al*., 1967
Giraffe (*Giraffa camelopardalis*)	Male		1174.3	61.9	Hall-Martin *et al*., 1977
	Female		791.8	56.6	Hall-Martin *et al*., 1977
Grant's gazelle (*Gazella granti*)	Male	6		60.5 ± 2.2	Ledger *et al*., 1967
	Female	5		59.0 ± 3.3	Ledger *et al*., 1967
	n.a.	84		55.0	McDowell *et al*., 1983
Hartebeest (*Alcelaphus buselaphus*)	Male	5		57.2 ± 1.4	Ledger *et al*., 1967
	Female	5		58.1 ± 2.0	Ledger *et al*., 1967
	n.a.	31		52.0	McDowell *et al*., 1983
Hippopotamus (*Hippopotamus amphibius*)	Male	4		43.0 ± 2.4	Ledger *et al*., 1967
	Female	4		41.9 ± 2.3	Ledger *et al*., 1967
Impala (*Aepyceros melampus*)	n.a.	41		57.4	Young & Van Den Heever, 1969
	Male	10		58.1 ± 0.9	Ledger *et al*., 1967
	Female	10		58.3 ± 3.0	Ledger *et al*., 1967
	n.a.		77	58.8	Van Zyl *et al*., 1969
Kob (*Adenota kob*)	Male	10		57.7 ± 1.9	Ledger *et al*., 1967
	Female	10		58.3 ± 2.9	Ledger *et al*., 1967
Kudu (*Strepsiceros strepsiceros*)	n.a.	18	236	56.6	Huntley, 1971
Lesser kudu (*Strepsiceros imberbis*)	Male	10		62.1 ± 1.5	Ledger *et al*., 1967
Mountain reedbuck (*Redunca fulvorufula*)	Male		30.2	55.3	Skinner, 1980
	Female		28.6	51.4	Skinner, 1980
Oryx (*Oryx beisa*)	Male			57.0 ± 1.7	Ledger *et al*., 1967
	Female	10		58.9 ± 2.5	Ledger *et al*., 1967

	n.a.			57.9	Van Zyl *et al*., 1969
Springbok (*Antidorcas marsupialis marsupialis*)	Male		36	56.0	Skinner *et al*., 1971
	Female		30	55.0	Skinner *et al*., 1971
	n.a.			52.6	Hvidberg-Hansen, 1971
Thomson's gazelle (*Gazella thomsoni*)	n.a.			60.0	Robinette & Archer, 1971
	Male	10		58.6 ± 2.1	Ledger *et al*., 1967
	Female	10		57.1 ± 2.1	Ledger *et al*., 1967
	n.a.	108		54.0	McDowell *et al*., 1983
Topi (*Damaliscus korrigum*)	Male	10		54.2 ± 1.9	Ledger *et al*., 1967
	Female	10		54.0 ± 2.1	Ledger *et al*., 1967
	Male			55.1	Mason, 1982
Warthog (*Phacochoerus aethiopicus*)	Female			52.9	Mason, 1982
	Male	10		54.7 ± 2.5	Ledger *et al*., 1967
	Female	10		55.7 ± 1.9	Ledger *et al*., 1967

(table continued on next page)

Table 16.4 Continued.

Species	Sex	No. in sample	Liveweight (kg)	Carcase dressing percentage	Source
Waterbuck (*Kobus ellipsiprymnus*)	Male	10		58.6 ± 1.4 58.9 ±	Ledger *et al*., 1967
	Female	10		1.8	Ledger *et al*., 1967
Wildebeest (*Connochaetes taurinus albojubatus*)	Male	10		50.0 ± 3.2 51.4 ±	Ledger *et al*., 1967
	Female	10		2.2	Ledger *et al*., 1967
	n.a.			57.7	Young *et al*., 1969
	n.a.	13		53.0	McDowell *et al*., 1983
Zebra (*Equus burchelli*)	Male	5		55.0	Ledger *et al*., 1967
	Female	5		53.6	Ledger *et al*., 1967
Zebu cattle (*Bos indicus*)	Male	10		58.0 ± 3.0	Ledger *et al*., 1967
	Female[a]	9		46.8 ± 1.4	Ledger *et al*., 1967

n.a. = not available.
[a]Thin cows.

and their carcases are properly prepared, their meat is perfectly acceptable (Talbot *et al*., 1965) and the meat of some species is of very high quality. In a study of the quality of the meat of seven wild game species in South Africa, Von la Chevallerie (1972) reported that springbok venison rated highest.

(6) The high unit value of some of the by-products of game cropping, particularly in countries where there is a developed tourist industry

Major by-products are hides and skins, horns, teeth, hair and ivory. Not all the hides and skins from game animals have a curio value, those of the kudu, wildebeest, eland and buffalo being used almost exclusively for leather production. The hides and skins of such animals as zebra, impala and many of the small gazelles and buck do, however, have an enhanced curio value. For example, in East Africa, the hide of the zebra is far more valuable than the meat. The overall economic value of these by-products may be very considerable.

(7) A tourist industry could also flourish in areas established for game-cropping purposes

There would, however, be difficulties. Game-cropping operations would have to be conducted at different times and on different sites from those used by the tourists.

Disadvantages

(1) Slaughtering and processing can be both difficult to organize and expensive to operate

There are two major possibilities. Either game can be shot on the range and processed in a mobile abattoir or they can be captured and transported to an abattoir located at a permanent site.

Von la Chevallerie & Van Zyl (1971) studied the effect of shooting on the quality of 74 springbok and impala carcases. They found that 14% of the total weight of carcase was unfit for human consumption on account of the bullet damage. They also noted that the stress of the chase and the death struggle had a detrimental effect on meat quality. Possibly the most efficient ways of shooting game on the range are either from a 'hide' or at night with the aid of a spotlight. It is certainly easier to organize the slaughter and processing of large animals, such as elephants, than it is of gazelles. Interesting information on the game-harvesting techniques used on a Kenyan ranch are provided by McDowell *et al*. (1983).

It is considered that, in general, the capture of game before slaughter would be a difficult

Fig. 16.1
Netting deer in Mauritius.

and expensive operation (Fig. 16.1). Apparently, blesbok and springbok are amenable to being driven but most attempts to drive game into funnel-type stockades have ended in failure.

If game meat is dried in the field to produce 'biltong' some of the major problems of field slaughter and processing can be overcome. This is, of course, one of the methods employed by poachers. Biltong is, however, no substitute for fresh meat and the total value of carcases used for biltong production is lower than that of carcases used for fresh meat production.

(2) Marketing difficulties

On account of the difficulties encountered in slaughtering and processing, most fresh game meat will inevitably be expensive. Under these circumstances, as the purchasing power of the indigenous people may not match their desire for game meat, poaching may become more popular than purchase. The possible exception to this situation is where large game animals producing relatively coarse meat, such as elephants, buffaloes and hippopotami, are cropped.

Export possibilities are usually restricted, not by the high price of game meat but by the incidence of epizootic disease in game-cropping regions; in particular foot-and-mouth disease (FMD) and rinderpest.

Even where there is a local demand for game meat, marketing difficulties may be serious. Local vested marketing interests may refuse to handle game meat so that a new and possibly expensive marketing organization has to be established.

(3) Game ownership

In most countries in Africa, and perhaps elsewhere, there are serious legal problems with regard to the ownership of game. Who is to benefit when hunting is superseded by game cropping in those countries where land is owned communally? The indigenous people, the organizers of game cropping or the government? Unfortunately, most indigenous people do not usually possess either the capital or the technical knowledge to organize their own game-cropping schemes. There is no doubt that if game-cropping schemes are to be successful in areas where land is held communally, then they must be organized in such a way that the indigenous people understand and see that they benefit economically. The emergence and role of community-based game cropping schemes in Africa is discussed by Barbier (1992).

(4) Reduced options for management

Compared with the husbandry of domestic livestock, that of game, where some aspects of semi-domestication are required, is difficult with limited managerial options. For example, there is difficulty in adjusting the numbers of game to the available feed supply, indeed in organizing any form of rotation of the animals. In general, treatment for disease is not recommended and action against parasites is contra-indicated as wild game usually possess some immunity that would be lost if there was regular treatment.

(5) Lack of knowledge of the biology of wild species

Although further knowledge of the wild game species is garnered annually there are still major gaps in our knowledge of their biology and particularly of their social behaviour.

(6) The cost of required infrastructure

Game cropping for sustained yield requires an extensive and expensive organization to establish the biological parameters of indigenous game species. In addition, the provision of slaughter and meat processing facilities in the field can be expensive if urban slaughter regulations are enforced.

Although there have been isolated game-cropping schemes in Africa where specific game populations have outgrown sustainable supplies, such as elephants in Kenya, hippopotami in Uganda and more general schemes in Burkina Faso, Ghana and Mozambique (Young, 1975), major internationally financed game-cropping projects have not been very successful. One of the first projects was the Luangwa Valley scheme in Zambia, funded by the United Nations Development Programme (UNDP). It commenced in 1965, but never attained its cropping targets and was closed in 1970 to be succeeded by an ecological study of the area. The UNDP then funded a project at Kajiado, Kenya that commenced in 1970. During the years 197174 there was a drought and the project was abandoned in 1974. The difficulties were that the productivity of the game was lower than expected, the government demanded elaborate sanitary and meat inspection facilities, there were unexpected disease problems and the large game that were cropped did not appear to be as efficient as cattle in converting fibrous herbage into edible meat.

The experience gained in these large projects and elsewhere, dampened enthusiasm for extensive game cropping and directed attention to the possibilities of managing game in smaller numbers of farms and ranches. Despite apparent advantages, game cropping under extensive conditions appears to have many disadvantages that were not very apparent in the 1960s and 1970s. These are the bureaucratic nature of past cropping schemes, their aim of harvesting only meata relatively low cost, perishable commodityand the lack of incentive for the indigenous people occupying the land. Some of these disadvantages are being dealt with in new communal development projects in Zimbabwe and Zambia (Barbier, 1992).

Management of Game on Ranches and Farms

Domestic livestock and game have coexisted in some tropical regions for very long periods, particularly in East, Central and South Africa. However, the game in these areas has never been managed and is likely eventually to disappear unless positive plans are made for its conservation and for sustained cropping.

In addition, there are ranches and farms in South, Central and East Africa where game animals graze within fenced areas, with or without domestic livestock, and where some degree of management is exercised.

Pioneer work on game ranching was conducted in Zimbabwe in the early 1950s, the results being published by Dassman (1964). In South Africa, according to Skinner (1973), farmers can exercise lawful ownership of springbok, blesbok and other game by enclosing them in ordinary paddocks. Progress had been rapid. According to Skinner (1989) there are more than 8200 farmers in South Africa deriving some income from game farming. Income may be derived in many ways: from the breeding and sale of live animals, slaughter for meat and/or trophies, hunting and tourism. In general some form of mixed husbandry is practised. Luxmoore (1985) stated that in South Africa, despite off-takes of up to 16%, game populations are increasing, trophy hunting leads to the conservation of rare species and habitats are improving.

Investigations into the possibilities of managing wild game and domestic livestock on ranches and farms have been conducted in Zimbabwe and Namibia (Fink & Baptist, 1992/4) and in Kenya (King & Heath, 1975; Thresher, 1980; Fink & Baptist, 1992/4). Since 1983 there has also been considerable interest in Latin America in the utilization of wildlife in rural development schemes (Thelen & van der Werf, 1995) with emphasis, since 1987 on use of the capybara (*Hydrochoerus* spp.), the cayman (*Cayman* *crocodilus*) and the green iguana (*Iguana iguano*).

At Galana, a 667 500 ha ranch in Kenya on which rainfall varies from 250 to 750 mm, stocking with game and domestic species provided some interesting comparative data (Table 16.5). Originally African buffaloes (*Syncerus caffer*) were included among the game animals, but it was found to be an inappropriate species under Galana conditions. The eland (*Taurotragus oryx*) was relatively unproductive at Galana where it was corralled at night, a time at which this animal normally grazes. The fringe-eared oryx (*Oryx gazella callotis*) appeared an appropriate species to ranch providing high quality meat and only requiring one-quarter of the water used by cattle.

Data from investigations at a ranch on the Athi plains in Kenya have been published by McDowell *et al*. (1983) and more recently by Fink & Baptist (1992/4). These data suggest that mixed game/domestic livestock ranches are liable to be more viable than game only ranches.

The advantages of mixed stocking:

(1) *The maximum utilization of biomass*. It is probable but not yet fully proven, that wild game and domestic livestock managed on the same area will provide the highest production of biomass per unit area as long as they possess different eating habits and food preferences so that they can utilize forage at all levels; grass, herbs, shrubs and trees.

(2) *Economy in infrastructure and inputs*. If additional and expensive internal fencing is not required with the game species allowed some freedom within the ranch, then in general water, mineral and veterinary inputs will be lower for game than for domestic livestock. In addition, some part of the infrastructure required by domestic livestock can probably be utilized when cropping game.

(3) *An opportunity for diversification*. If game cropping is limited to certain seasons and specific areas of the ranch there is a chance to diversify by providing photo-opportunities, trophies and souvenirs for tourists.

The disadvantages:

(1) *Animal health*. Game animals may act as a reservoir for epizootic disease and parasites that could spread to the domestic livestock. For example, in Africa the reservoirs for malignant catarrhal fever and the SAT type of foot-and-mouth disease virus are respectively the wildebeeste and the African buffalo.

(2) *Managerial difficulties*. Management becomes complex. There is difficulty in maintaining proper stocking rates as wild game

Table 16.5 Comparative water intake, reproduction and slaughter data of domestic and game animals at the Galana Ranch, Kenya. (*Source*: King & Heath, 1975.)

Species	Water intake Litres/day	As % of cattle[a]	Age at first parturition (year)	Parturition rate (%)	Age at slaughter (year)	Mean liveweight at slaughter (kg)	Cold dressed carcase as % of liveweight
Boran cattle	40.0	100	3.2	83	2.8	350	52
Eland[b]	20.7	60	3.7	57	3.2	300	55
			3.0	100	2.5	300	55
East African goat	3.0	50	1.2	108	1.0	35	46
Dorper sheep	3.6	45	1.3	89	1.0	40	45
Oryx	4.8	25	2.5	102	2.0	135	57

[a] On comparative weight basis.

bSecond row refers to data from the Rift Valley in Kenya.

may not always accept the discipline imposed by internal fencing. It is also difficult to maintain wild game herd structures at their most effective level. For example, as cropping is usually accomplished by shooting the game at night when detailed identification is difficult, the sex ratio in a herd may be so altered as to lead to low reproductive rates in the next season.

(3) *Marketing*. In some countries it may be difficult to find a profitable market for game meat, either because a suitable market is at a considerable distance from the production site or because local retailing and hygiene laws are so restrictive that the marketing of game meat becomes uneconomic.

Domestication of Wild Game.

It is an astonishing fact that only a very few of the total number of available species have ever been domesticated and that almost all present domestic species were domesticated during the Neolithic revolution. There is some evidence that man did attempt to domesticate some additional species (Zeuner, 1963), but that he failed or at least lost interest. For example, the Egyptians semi-domesticated the addax. There are pictures in an Egyptian tomb dated 4500 BP showing addax wearing collars and tethered to stakes. It must be assumed that, until recent times, the few species that were domesticated satisfied man's need for domestic livestock.

With the present need to exploit all ecosystems to the maximum, it is perhaps a suitable time to consider further attempts at domestication.

Work has been conducted both in Africa and the former USSR on the domestication of the eland (*Taurotragus oryx*). Posselt (1963) reported that a herd of approximately 20 eland had been domesticated in Zimbabwe. He stated that adult males and females weighed 730 kg and 540 kg respectively. Heifers calved at 2 years of age and the gestation period was approximately 34 weeks. The dressing-out percentage of the carcases of mature stock was 5860. In South Africa, where eland were fed indoors, the average liveweight gain was 0.5 kg/day, and calves attained a liveweight of 136 kg at 5 months of age.

In the 1970s a further attempt to domesticate eland was made by the African Wildlife Leadership Foundation at the Galana Ranch in Kenya. The attempt was abandoned as it was found that the eland's feeding behaviour could not be accommodated within the ranch managerial system.

Treus & Lobanov (1971) reviewed details of the acclimatization and domestication of eland at Askaniya-Nova in the southern Ukraine. The attempt at domestication began in 1890, was accomplished by hand feeding of the young and proceeded to the point when experimental milking could begin in 1947. The eland were allowed to graze freely during summer months and were penned indoors during the winter months. A total of 44 females was milked between 1947 and 1971. The average lactation yield was 200 kg, the lactation period varying from 100 to 390 days. The peak milk yield of the best miler was 6.9 kg/day. The average fat and protein percentages of the milk were 11 and 8, respectively. Mature males and females weighed up to 800 kg and 500 kg, respectively. The authors stated that the meat was of excellent quality and that the hide was valuable.

Skinner *et al*. (1971) suggested that there is evidence that two subspecies of the springbok, *Antidorcus marsupialis marsupialis* and *A. marsupialis angolensis*, could be at least semi-domesticated as they are more tractable than most antelopes and can be herded in paddocks.

Attempts are also being made in Africa to domesticate antelopes, Thomson's gazelle, the red letchwe, the oryx and the buffalo.

For example, at the Galana Ranch in Kenya the possibility of domesticating the fringe-eared oryx (*Oryx gazella callotis*) has been investigated (Thresher, 1980). It was discovered that insufficient was known as to the social habits of this animal. Apparently, for proper management, oryx herds have to number less than 50. A situation that considerably increases managerial costs.

Consideration should also be given to the domestication of species other than ungulates, such as the turtle in the Caribbean, the grass cutter in West Africa and the capybara in the *llanos* of Colombia and Venezuela. Kyle (1987) reported that the tapir (*Tapir terrestris*) has been semi-domesticated by the *Conibos* Indians of Peruvian Amazonia.

The advantage of using domesticated or semi-domesticated wild game species is that animal health, slaughter, processing and marketing problems are minimized. The immediate disadvantage is that domestication is a slow and tenuous process and that, even when a wild species has been domesticated, it may be many years before a sufficient number of animals is available for economic exploitation.

Wild Game Products

Meat

Game carcases differ markedly from the carcases of domestic livestock. The major difference is that the average fat content of the carcase is much lower and the lean meat content correspondingly higher. Consequently, the lean constant, obtained by expressing the weight of lean meat in a carcase as a percentage of the total carcase weight, differs markedly as between game and domesticated livestock (Table 16.6). This constant appears to be unvarying irrespective of age, liveweight and killing-out percentage.

Table 16.6 A comparison of the lean constants of some domestic livestock and game animals. (*Source*: Ledger, 1963a, 1964a.)

Species	Lean constant
Goat	31
Bos taurus cattle	32
Bos indicus cattle	33
Wildebeest	42
Oryx	45
Thomson's gazelle	46

The killing-out percentage of some game animals is comparable with those of domestic livestock (Table 16.4). Surprisingly, the percentage of the hindquarters in game animals is as good, if not better, than in indigenous cattle. Ledger (1963a) reported that it was 58% in Thomson's gazelle compared with 53% in Boran cattle, while Ledger & Smith (1964) reported that all except the most mature Uganda kob possessed a better hindquarter percentage than Boran cattle.

It may be concluded that some game animals kill out at almost as high a percentage as well-managed cattle and that their carcases possess a high proportion of hindquarters. The meat is leaner than that of cattle and is therefore not so succulent but, according to Ledger (1963a), it is usually tender and possesses a good flavour. These observations from East Africa have been confirmed in South Africa by Von la Chevallerie (1972).

Hides and Skins

Many game animals produce very valuable hides or skins. These can be a by-product of a game meat industry, of hunting or game farming. The high value of some reptile skins and the possibilities for reptile farming have already been mentioned.

Other Products

There are many other valuable game products, such as hair, bone, horn and specialized products like the musk obtained from the musk deer. The trade in some of these animal products has had a disastrous effect on wildlife. For example, the search for rhinoceros horn, used to make Yemeni dagger handles and Chinese potions, is leading to the extermination of the species. If wild animals that produce commercially valuable products cannot be exploited in some sustainable manner, then they must be adequately protected from extermination. This is to some extent being accomplished by countries signing the Convention on International Trade in Endangered

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Species of Wild Fauna and Flora (CITES) agreement.

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17
Microlivestock

Introduction

The term microlivestock is used to include poultry and smaller breeds of conventional domesticated livestock (National Research Council, 1991) as well as for snails, rodents and more conventional species such as the rabbit, guinea pig and bees. Other microlivestock could include, among a list of some 150 candidates, yet more rodents, reptiles, insects and earthworms.

Microlivestock can be an important subsystem where land is scarce and parts of the community, particularly women and children, lack adequate income and nutrition. Economic niches not available to larger species are occupied by microlivestock. They are useful for people outside or at the margins of the cash economy because they cost little to buy, are a relatively small financial risk, produce rapid returns on investment and allow very flexible operation. They also provide a steady source of food or income, generate employment, are likely to be successful because they are numerous, are easily transportable, and are often efficient converters of feed to protein for humans. Other benefits include the small size of the package, efficient use of space, low capital needs for housing, use of nonconventional feeds, easy management, and production of numerous by-products. The meat of some species is low in fat, high in protein and has low cholesterol levels which further add to the quality of life in general.

It is claimed for some species, for example butterflies in Papua New Guinea, that they assist environmental conservation and biodiversity as rare plants are grown to feed them (Mercer, 1994). Opportunities for the tropics to provide exotic foods to the developed world also abound. Indonesia, for example, supplied frogs' legs to the value of 25 million ECU to the European Union in 1992 with China, Bangladesh and Vietnam also being important exporting countries (Hardouin, 1994). Not all the species covered in this chapter have actually been domesticated or exploited to any great extent but all have the potential to add to the economic viability, diversity and sustainability of tropical livestock production systems.

Rabbits

Species and Distribution.

Rabbits belong to several genera in the subfamilies Leporinae (which includes the similar hares, *Lepus* spp.) and Palaeologinae of the family Lepidae in the order Lagomorpha in the superorder Glives. 'Rabbits' (including the genera *Entalagus*, *Prentalagus*, *Pronolagus*, *Romerolagus*, *Macrotolagus*, *Coprolagus*, *Nesolagus*, *Brachylagus* and *Ochotona* (family Ochotonidae) occur throughout the world. Most rabbits in the broad sense have developed a digestive system, known as coprophagy, analogous to rumination. Feed is partially digested, voided, the faeces reingested and digestion then completed.

The true rabbit, *Oryctolagus cuniculus*, comprises several subspecies that were originally native to southwest Europe and North Africa. It was known to the Phoenicians, in Spain about 3000 BP (before present) and it spread throughout the Roman empire as a game animal. It was later kept in stone-walled parks, called 'leporaria', for sport and to provide fetuses and newborn rabbits, known as laurices, for consumption by the Romans and later by monks. These 'leporaria' are the origins of many European warrens where large numbers of rabbits are still found. Rabbits have been introduced elsewhere recently, notably to Australia where (as everywhere) they are a serious pest and compete with standard livestock for grazing.

Rabbits were truly domesticated about 400 years ago when some European feudal systems (in which only landowners had the right to own rabbits) were abolished and keeping rabbits in hutches or cages became widespread. Rabbits as domestic animals have undergone several cycles of popularity and decline, being especially popular during wars when other meat was not easily available. Precocity and prolificacy enable very rapid population expansion. Europe remains the centre of production in terms of overall volume but consumption per person is highest in tropical and subtropical countries.

Some species that are not lagomorphs show similar morphology to the rabbits. The vizcacha (a Spanish word from the Quechan Indian language), *Lagidium viscacia*, a rodent of the upper Andes, is native to southern Peru, most of Chile and parts of Bolivia and Argentina. It has a head and ears that could lead to it being confused with the true rabbit but its very short front legs and long tail (Fig. 17.1) serve to distinguish it. The long greyish-coloured fur, often tinted with a rich brown hue, is similar in composition to, but not as valuable as, that of the chinchilla, to which animal it is very closely related.

Rabbits are relatively easy to rear, manageable in small units and do not necessarily compete directly for human food. They are eminently suitable to smallholder production and, while there may be some initial resistance to eating them, there are no major entrenched taboos.

Biology

Wild rabbits are gregarious, sedentary animals that live in underground burrows or warrens and maintain a territory whose area varies in relation

Fig. 17.1
'Vizcacha', *Lagidium viscacia*, at 4470 m altitude in
the Andes of northern Chile.

to feed supply. Territory, and rabbits, are marked by the aid of a gland under the chin and with urine. Females withdraw to a private burrow at parturition where the young are normally suckled once a day. Females outnumber males in the wild and, whether they have young of their own or not, attack the young of other individuals. These facts are important for housing design and construction in captivity. In the wild, danger is signalled by thumping the hind foot, when all the group rapidly takes evasive action by disappearing into the warren. Disturbances in rabbitries elicit the same or similar reactions that greatly affect potential productivity.

Female rabbits generally attain puberty at 7075% of adult weight and are capable of breeding at about 4 months of age. Under natural temperate zone conditions there is considerable reproductive seasonality, probably resulting from the combined effects of daylength and temperature. Most does are pregnant in England in March and again in May and June with very low levels of breeding (following a slight rise from July to August indicating a third litter) from September to December. Pregnancies increase to the spring peak from January. Temperature is the most important variable acting on reproduction in the tropics.

Rabbits are induced ovulators and eggs are shed following stimulation by coitus. Does are considered in oestrus when they accept service and in dioestrus when they do not. Oestrus does adopt a characteristic back-down, hindquarter-raised posture. Unlike most other animal species, pregnant rabbits will accept mating and 80% of does return to heat by the twentieth of the 3132 day gestation period. Simultaneous pregnancies ('superfoetation') from mating during pregnancy are known in the hare but not in the rabbit.

Spermatogenesis begins at 67 weeks but there are no spermatozoa in the ejaculate until about 15 weeks. Sperm counts in mature rabbits are in the range 150500 × 106/ml and ejaculate volume is 0.30.6 ml. Bucks mount a female several times. Semen volume decreases successively but sperm concentration increases from first to second ejaculation. Sexual foreplay lasts 20120 seconds and the sexual act itself is very short. Rabbit litters are as many as 20 young but 312 is a common range. Mortality is very high under natural conditions. Growth is rapid in surviving young. Milk production reaches a peak about 3 weeks after parturition and ceases by about 7 weeks. Rabbit milk is very rich, with 26% dry matter, nearly 10% fat and 14% proteins.

Rabbits are grazers in the wild but accept a variety of feeds under domestication and very high ratios of liveweight gain to feed can be achieved.

Carcase and Nutritive Characteristics

Most tropical production is for meat and is mainly for home use. China exports about 30 000 t of meat per year to the European Union. Uruguay has a small export trade, which was about 40 t in 1980. Modern fast growing breeds, such as California Hyline and New Zealand White, reach weights of 2.2 kg at 8090 days. Dressing percentages are 6070% and increase with age, independently of weight. The higher value hindquarters and loins comprise about three-fifths of the carcase. Carcase yield is slightly less in animals fed bulk roughage feeds as this tends to cause development of the digestive tract.

Rabbit meat has a bland flavour. Tenderness diminishes with age and juiciness depends largely on the fat content. Protein is higher than in most other meats at about 21% but fat (8%) is low. In human dietary terms, meat is low in stearic and oleic acids with a high proportion of polyunsaturated linolenic and linoleic acids. Some vitamins, notably nicotinic acid and calcium pantothurate, are higher in rabbit than in other meats and calcium and phosphorus are also high. Rabbit meat is a good source of protein and some other essential elements and is relatively low, at 160 kcal/100 g meat, in energy.

Other Products

Skins and Angora 'wool' are produced by rabbits in addition to meat. Australia exports some rabbit skins from wild animals killed in control operations and it is possible that a small proportion of these originate in the tropics. Angora wool occupies a special position in the world textile trade. China is by far the largest producer of Angora wool at about 2000 t per year. Argentina, Korea and India also produce small amounts of Angora wool. There is a very small Angora rabbit wool industry in Bolivia (Fig. 17.2) where

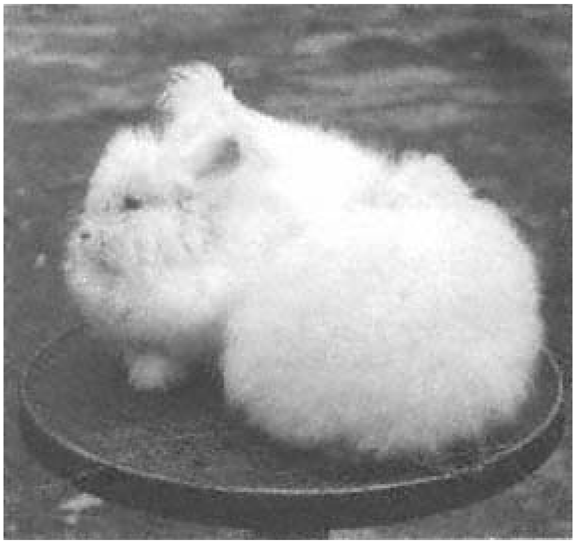

Fig. 17.2
Angora rabbit being tested for fibre production at
Oruro in western Bolivia.

yields of 100150 g fibre are produced every 70 days, the product being sold for export at about US$30 per kilogram in early 1991.

Management Systems

Rabbits are very suitable for intensive management systems. Hybrid lines capable of high reproductive rates and very good feed to meat conversion ratios (Table 17.1) are readily available. For production other than for home use and a small surplus for sale, maximizing the reproductive rate is the major factor affecting productivity.

Management is possible at three reproductive levels (Fig 17.3). In extensive systems gestation and lactation are not concurrent events; young are weaned naturally at 56 weeks, does are bred after weaning and give birth every 2.5 months. In semi-intensive cycles, does are bred 1020 days after kindling and young weaned at 45 weeks. There is some overlap of gestation and lactation but for 6065% of the time does are only pregnant or only lactating. In intensive systems, does are served on the day, or at the latest within 4 days, of kindling. Weaning should take place not later than 28 days after parturition and a reproductive cycle of less than 35 days is possible.

The most intensive breeding system should only be attempted where feed conditions are optimal. Progressive breeders adjust cycles to feed availability and doe condition. Females with 78 young are usually mated immediately

Table 17.1 Production characteristics and trends in intensive rabbit systems in Europe.
(*Source*: adapted from Lebas *et al*., 1986.)

Parameter	Year			
	1950	1960	1970	1980
No. sold/breeding female/year	<25	30	45	60
Interval between litters (days)	>90	70	54	42
Ratio concentrate feed:gain		6.0	4.5	3.6
Rabbit type	Unselected pure breeds		Pure breeds × improved bucks	Hybrids
Man-hours/doe/year	16.0	16.0	10.0	7.5
Labour (min)/carcase (kg)	27.0	22.0	9.5	6.2
Unit size	80100	100150	200250	3501000

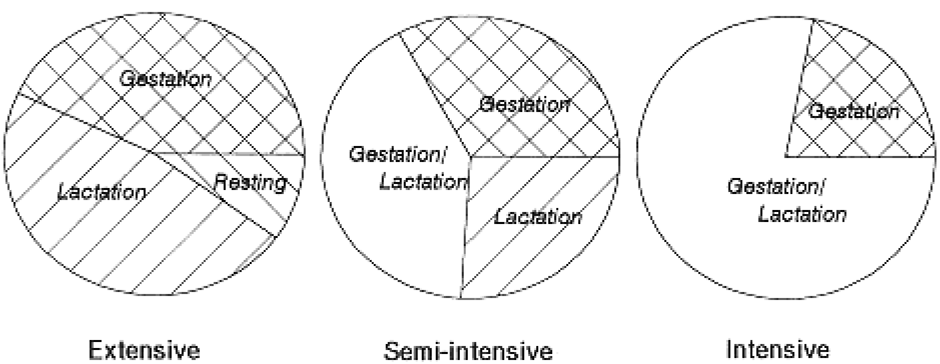

Fig. 17.3
Levels of reproductive intensity in modern rabbit husbandry systems.
(Source: adapted from Lebas *et al*., 1986.)

whereas those with larger litters are held back a few days. Feed intake and nutritional needs vary with age and reproductive status (Fig. 17.4) and less energy is needed in warm than cold conditions. At 30°C, energy demand is 50% lower than at 5°C but weight gains are also reduced by about 30%. Water requirements are greater at higher temperatures.

Production systems in the tropics are still at an early stage of development. In the Caribbean, for example, the levels of production (Table 17.2) are comparable to those achieved in Europe in the 1950s (cf Table 17.1). It should be possible, however, to increase production and productivity very rapidly by drawing on European experience and adapting it for the tropics.

Rabbits are sometimes selective feeders but will eat a wide variety of plants. In modern systems a series of standards has been established for different production stages (Table 17.3). Protein quality, determined by essential amino acid levels (especially methionine, lysine and

Table 17.2 Rabbit performance in the Caribbean. (*Source*: Rastogi, 1990.)

Trait	Mean
Reproduction	
Litter size (total young) (No.)	5.0
Litter size (born alive) (No.)	4.5
Litter size (weaned) (No.)	3.5
Pre-weaning mortality (%)	20
Age at first mating (months)	6.0
Period between parturitions (days)	80
Litters/year (No.)	4
Young/doe/year (No.)	1216
Reproductive life (months)	1218
Age at culling (months)	1824
Growth	
Birth weight (g)	45
Weaning weight (28 days) (g)	320
Weight at 13 weeks (g)	1600
Pre-weaning daily gain (g)	10
Post-weaning daily gain (g)	22
Mature weight (g)	3000
Dressing % at 13 weeks	52
Post-weaning feed efficiency (concentrate:gain)	3.6

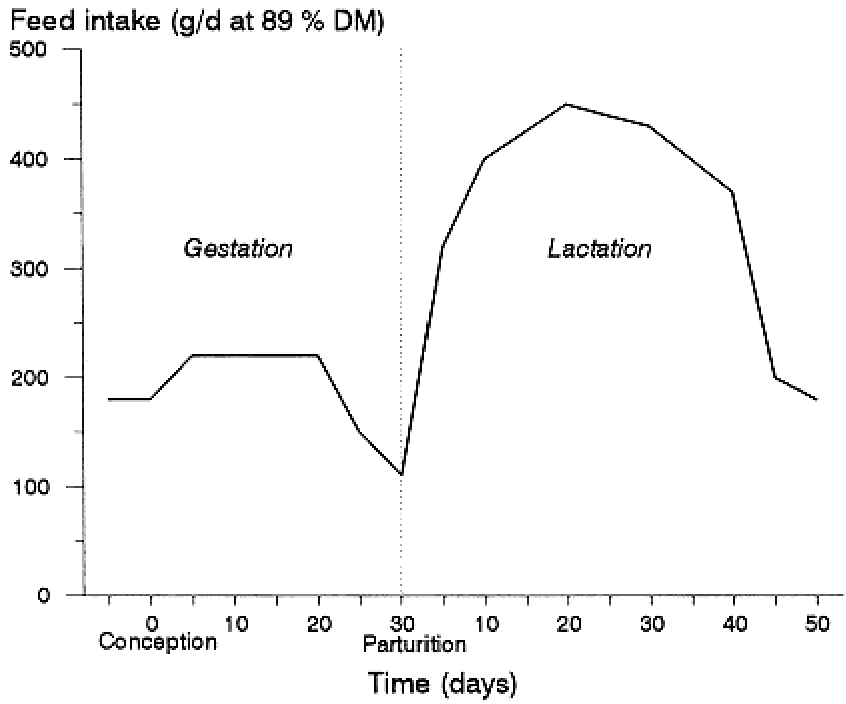

Fig. 17.4
Feed intake of rabbits at different stages of the production cycle.
(Source: adapted from Lebas *et al*., 1986.)

Table 17.3 Nutritional requirementsa of rabbits in different physiological states. (*Source*: adapted from Lebas *et al*., 1986.)

Feed component	Physiological state			
	Growing (412 weeks)	Lactating	Pregnant	Dry doe
Crude protein (%)	16	18	16	13
Crude fibre (%)	14	12	14	16
Indigestible crude fibre (%)	12	10	12	13
Fat (%)	3	3	3	3
Calcium (%)	0.4	1.1	0.8	0.4
Phosphorus (%)	0.3	0.8	0.5	0.3
Iron (ppm)	50	100	50	50
Manganese (ppm)	8.5	2.5	2.5	2.5
Vitamin A (IU/kg)	6 000	12 000	12 000	6 000
Vitamin K (ppm)	0	2	2	0
Niacin (ppm)	50	0	0	0
Digestible energy (kcal/kg)	2 500	2 600	2 500	2 200
Metabolizable energy (kcal/kg)	2 400	2 500	2 400	2 120

a Minerals and vitamins have been selected to show range in values at different stages.

arginine), is as important as quantity. Unbalanced proteins reduce growth rates by up to 14% and increase the normal feed conversion ratios of 3:1 to 4:1 for intake:gain. Attempts to replace true proteins with non-protein nitrogen, such as urea, have not been successful.

Rabbits grow best on feeds with 220240 kcal digestible energy (DE) per kg W0.75. Lactating does require as much as 360 kcal DE/kg W0.75. To achieve these values, energy density must be in the range 22003200 kcal DE/kg feed. In lower intensity and smallholder systems many local plants can be used to reduce costs. In Malawi a roughage supplement of *Amaranthus* (20% protein) to a concentrate ration of 39.5% maize grain, 26.0% maize bran, 34.0% groundnut cake and 0.5% salt allowed does to produce 20 young per year and young rabbits to grow at 15 g per day for up to 16 weeks. Groundnut haulms are fed in Burkina Faso as well as *Brachiaria ruziziensis. B. mutica* is used in the Philippines and could prove useful elsewhere in the tropics. Cassava leaves and peel are used in Ghana but both need balancing with protein and fibrous feeds. Bananas, coconuts, prickly pears, potatoes and many legumes and grasses are also fed to rabbits in many parts of the tropics.

Rabbits are ideal for small farmers and landless labourers. The small capital requirement, local feed availability and use of surplus household labour make rabbit rearing an attractive and profitable operation. Rabbit meat is a small proportion of total meat consumption almost everywhere but is highest in some tropical and subtropical countriesMalta (4.30 kg per year), Cyprus (0.89 kg), Egypt (0.22 kg), Ghana (0.20 kg), Peru (0.13 kg), Algeria and Colombia (0.12 kg each) and Mexico (0.60 kg). Where available, the proportion it contributes to total family animal protein consumption increases at times of economic difficulty. Lack of government-support policies, inadequate marketing and processing channels, poor extension services and inadequate adaptive research for local feed, health and management conditions are problems associated with tropical rabbit production.

Guinea Pigs

Species and Distribution

Guinea pigs belong to the genus *Cavia* of the family Cavidae in the order Rodentia. They are related to lagomorphs, both orders being in the superorder Glives. Domestic guinea pigs are also known as cavies, a corruption of the Quechan 'cuy', the onomatopoeic South American Indian word derived from the animal's alarm call.

The domestic species *Cavia procellus* is native to the South American Andes. It had already been domesticated and was familiar to the aboriginal Inca and other populations of the highlands of Peru, Ecuador and Colombia by the time the Spaniards arrived in the New World. Guinea pigs rarely weigh more than 1 kg at maturity. They do not burrow although they have four strong claws on the front feet and three on the hind. Several domesticated types have developed. The Peruvian is a rather large variety with long silky hair. The English or Bolivian breed is a short-haired type. An 'Abyssinian' type has hair in a series of whorls.

Biology

Guinea pigs are gregarious and live in small family groups in dwellings of straw or other vegetative material above ground. They are intrinsically shy but under domestication are habituated to humans.

Guinea pigs are precocious and females are capable of breeding at 23 months. The life span rarely exceeds 2 years but even with a long gestation period in relation to mature size a total of seven or eight litters per lifetime is not unusual. Litter size is in the range 15, but is usually two for primiparous females and three or four for multiparous ones. In Cameroon guinea pigs had their first litter at 134 days with subsequent litters being born at intervals of 6368 days; first litters averaged 1.6 young with later ones averaging 2.0 (Fotso *et al*., 1995). Young are born at an advanced stage, with full fur and open eyes, and capable of feeding on green feed almost immediately. Weaning occurs naturally at about 14 days, by which time females are again pregnant. Growth is rapid and mature weights are reached at about 3.5 months (Fig. 17.5). Growth rate is affected by several factors, including litter size, breed and location but both sexes have similar weights. In Cameroon females produced 3.1 kg liveweight of young per year equivalent at a dressing percentage of 6673% to about 2.1 kg of edible carcase.

Carcase and Nutritive Characteristics

Dressing percentage is about 65%. The meat is very dark in colour and has a strong but pleasant gamey taste. In South America, hair is removed with boiling water and the animal then cooked in its skin. The meat is low in fat and has low cholesterol levels and is therefore suitable for speciality markets.

Management Systems.

Guinea pigs are often kept as pets and are important laboratory animals. In their native South America they are a major food for the indigenous population. An estimated 20 million guinea pigs in Peru produce about 16 000 t of meat per year, equivalent to about 80% of sheep meat output. Recent work in Peru has increased the weight at 6 months from 0.75 to 2.00 kg with each breeding female producing some 5 kg of carcase weight per year (Morale, 1994).

Little special housing or care is needed by guinea pigs and they are apparently happy living intimately with the family. There may be some hidden danger in this, however, as in many places they are heavily infected with liver fluke *Fasciola hepatica* which is a zoonose that can be transmitted to humans (Gamarra, 1996). They also do well in more intensive systems (Fig. 17.6). While not yet so well developed in other parts of the tropics, guinea pigs offer good opportunities for improving smallholder income, nutrition and welfare without competing for common and limited resources.

Cane Rats and Grass Cutters

Species and Distribution

Cane or African giant rats of the genus *Cricetomys* and grass cutters of the genus

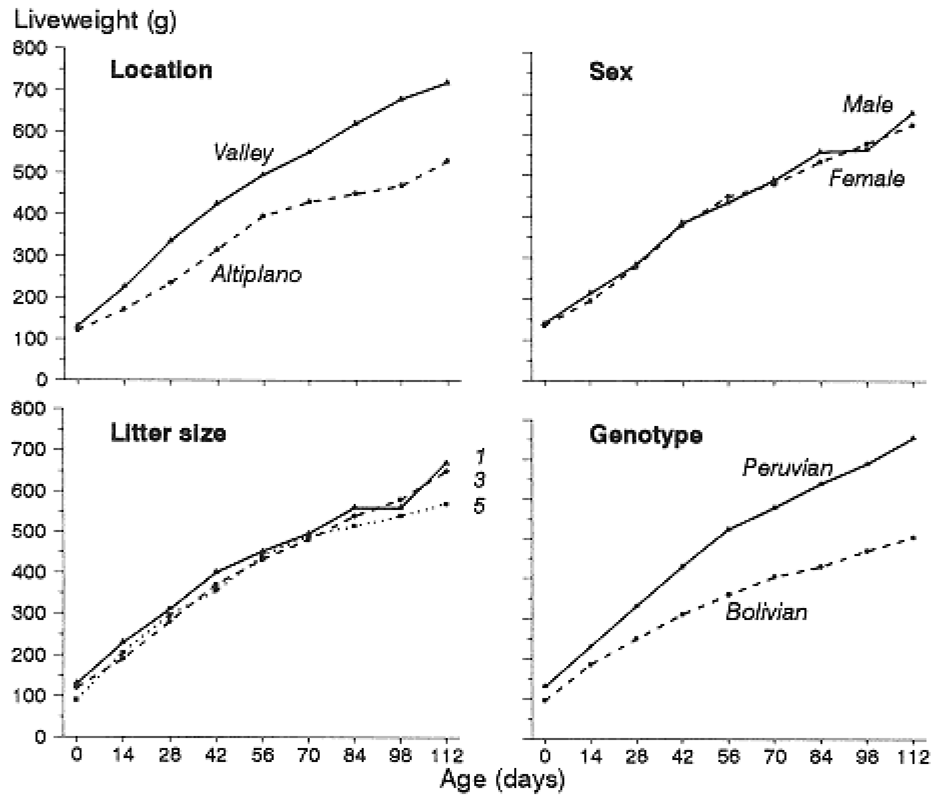

Fig. 17.5
Patterns of growth as affected by various factors in guinea pigs in Bolivia.
(Source: B. Lopez, pers. comm., 1991.)

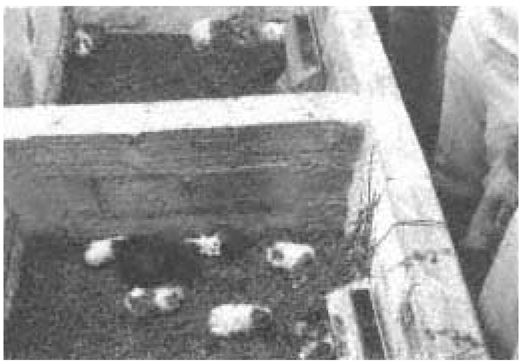

Fig. 17.6
Guinea pigs in a modern management system at
the Technical University of Oruro, Bolivia.

Thryonomys are widespread in Africa in all except the driest areas. They appear to be commoner in West Africa than elsewhere but this is possibly because they are seen more often offered for sale on roadsides and in markets due to their use as food.

The West African rat that is most used for food is *Cricetomys gambianus* which is mainly a species of the savanna areas. *Cricetomys emini* is also used for food but is more restricted in distribution and occurs mainly in rainforests. Giant rats are burrow-dwelling, usually solitary and apparently prefer damp or wet places, although the few reports on their ecology are conflicting. The West African grass cutter, *Thryonomys swinderianus*, is a large nonburrowing rodent.

Biology

Cane rats usually mate at night, copulation lasting about 1015 seconds with the total sexual act occupying 23 minutes; multiple mating occurs. Puberty is reached at about 2324 weeks, the oestrous cycle is 4 days and gestation about 28 days. Litter size averages three young, in the range 25, and six litters a year are possible. Grass cutters breed all year round in Ghana but one litter, ranging in size from two to four, per year is usual. Gestation is very long, about 155 days, and is probably related to development of the young at birth.

Cane rats are medium-sized rodents weighing about 1 kg at maturity (Table 17.4). Daily weight gains under experimental conditions average about 10 g from 4 to 10 weeks old. Young are naked at birth and virtually helpless until 28 days and the eyes do not open until about 21 days. Grass cutter young are born at an advanced stage with the eyes already open. They are fully furred and capable of moving and feeding very shortly after birth. Mature grass cutters weigh as much as 6.8 kg.

Cane rats and grass cutters are mainly herbivorous but will eat many kinds of food. In the wild, cane rats eat mainly palm fruits and tubers, particularly yams, plus a variety of other fruits, seeds and insects. There are some differences in dietary preferences between males and females. In captivity cane rats will eat yam, cassava and plantain peels, maize chaff and cocoyam and yam tubers with apparent digestibilities of 1272% of the dry matter at a feed conversion ratio of 2.63.3 to 1.

Carcase and Nutritive Characteristics

Male cane rats with average weights of 1033 g and females weighing 919 g kill out at 51.5% with low fat and relatively high protein contents. Grass cutters kill out at as much as 64% with a meat to bone ratio of 3.5:1.0, the flesh comprising 70% moisture, 19% protein, 9% ether extract and 1% ash.

Management Systems

Most cane rats and grass cutters eaten in the home or sold commercially are captured in the wild. They command much higher prices in West Africa than domestic red meat animals and poultry. Wild stock are being depleted due to indirect predation by humans cultivating more and more land and by direct predation for food and to generate income.

Several trials have shown the feasibility of 'domesticating' both species. At captivity, and down to the fourth generation, they show psychological problems including aggressiveness to each other and fear of their keepers. At these early stages, cannibalism of the young by the parents, especially the male, is common and 40% may be lost unless steps are taken to overcome the problem; 'cainism'the eating of siblingsis also common. In Nigeria animals kept in suitable

Table 17.4 Body composition of the cane rat *Cricetomys gambianus*. (*Source*: adapted from Ajayi, 1977.)

Parameter	Males (*n* = 10)		Females (*n* = 7)	
	Range	Mean	Range	Mean
Standard length (headanus) (mm)	297400	342	236430	323
Tail length (mm)	280385	344	300380	350
Total length (mm)	627723	686	620799	673
Liveweight (g)	6501425	1033	6921212	917
Skin weight (g)	62192	122	83185	123
Head without skin (g)	3467	45	4459	45
Tail without skin (g)	445	31	2338	31
Heart (g)	410	5.5	38	5.0
Lungs and trachea (g)	425	11.6	516	10.5
Liver (g)	1843	32.0	1541	27.4
Kidneys (g)	214	5.7	113	5.0

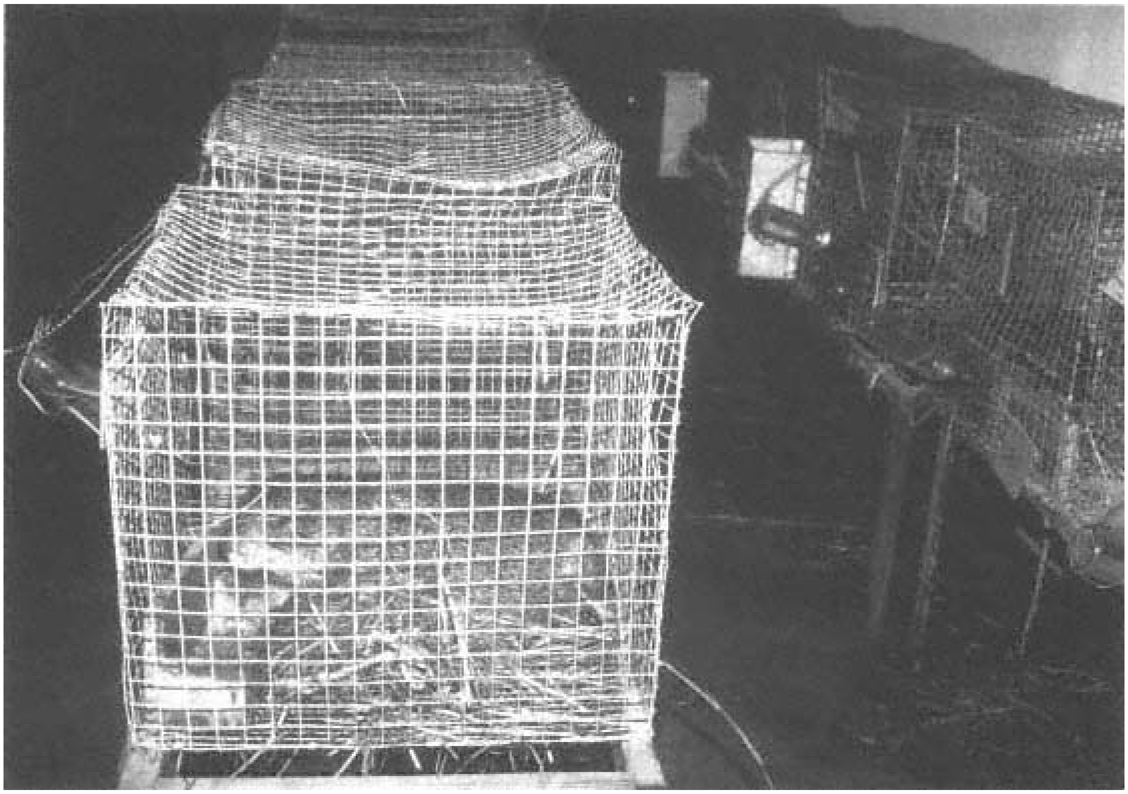

Fig. 17.7
Grass cutters being reared in cages at an experimental development project in Benin (note feeding bottles).

housing and adequately fed have been bred to fifteen generations. In Benin a successful development project has communal pens for breeders and growing stock but finishes sale animals in individual cages (Fig. 17.7).

Capybara

Species and Distribution

The capybara, *Hydrochoerus hydrochaeris*, belonging to the suborder Cavimorphae, family Hydrochoridae, subfamily Cavioidae, is the largest rodent in the world (FAO, 1994). The capybara is indigenous to, and widely distributed in, lowland tropical South America where it is known by several local names. This semi-aquatic animal is rarely found more than 500 m from open water (Ojasti, 1991). The subspecies *H.h. hydrochaeris* extends from the eastern plains of Colombia, through Venezuela, Guyana, French Guiana, Surinam to the Amazonian parts of Ecuador, Peru and Bolivia, thence the whole of Brazil, Paraguay and Uruguay and to the northeast of Argentina. The subspecies *H.h. isthmius* has a separate distribution in Panama, western Colombia, western Venezuela and the Pacific coast of Ecuador.

On one ranch in the Venezuelan 'llanos' a census showed about 40 000 capybara on 50 000 ha. Current world numbers are not known but in some areas they are on the verge of extinction in the wild due to overhunting and persecution by farmers and ranchers who regard them as competitors with domestic stock and as carriers of disease. In floodplain ecosystems, however, they complement cattle as they prefer to feed on swamp grasses that are not generally accessible to cattle.

Biology

Capybara vary in length from 1.0 to 1.5 m and stand 5065 cm at the shoulder. Animals from the northern part of the range are smaller, weighing 4550 kg, with the size increasing progressively southwards so that animals from Argentina and northern Brazil may weigh as much as 80 kg. As with guinea pigs they do not burrow and also have four toes on the front feet and three on the hind. Webbing between the toes assists the animals in swimming. In addition to being strong swimmers, capybara can run at great speed over distances of 200 m. They do this when frightened, usually in the direction of water to which they take and can remain submerged for up to 10 minutes. It is mainly a nocturnal animal and darkness helps it to escape from its predators, including man, by whom it is much persecuted.

Capybara are very social. Groups maintain a loose territory where they live, eatthey are mainly grazers but also browse shrubsand breed and which is marked by the dominant male (Macdonald *et al*., 1984). During dry periods with less open water groups are large and contain many families. With abundant water groups are smaller and comprise closely related animals. These second groups persist and reform from year to year. Old and weak animals are driven away from the groups to make them less vulnerable to predation. A typical group includes three or four males and six females plus young. Within the group males feed on the outside and guard and protect the females and young in the middle.

The dominant male is the only one that mates with the females. Copulation usually takes place in water and breeding takes place all year round. First young are born when females are about 2 years old. The gestation period of 150 days allows about 1.8 litters per year in the wild that average about 4.7 young (each weighing 1.75 kg at birth) per litter. It has been calculated that their 'reproductive efficiency' (weight of young produced per year divided by the weight of the dam) is 0.33 compared to an efficiency in cattle in the same environment of 0.04.

Capybara, like all rodents, are monogastric animals whose digestive system is well adapted to coarse materials although they are selective feeders and probably always have an intake that is higher in quality than the average on offer. The large caecum, with a capacity similar to that of a sheep's rumen, is the main site of digestion. The extremely efficient method of chewing which reduces its feed intake to very small particles assists initial digestion and further nutrients are extracted as the animal is also coprophagous.

Carcase and Nutritive Characteristics.

Capybara meat is a traditional and much-liked food in much of South America. It is white in colour and could compete with pork in some parts of the meat industry. The meat has been used to make several types of sausage (González-Jimènez, 1977). Although it is cooked in many ways (by boiling, frying, grilling and roasting), most is eaten in the dried and salted form. The fresh carcase dresses out at about 52% but this is reduced to about 17% of the initial liveweight in the dried form. The fresh meat is low in calories and fat but high in protein (Table 17.5).

Table 17.5 Comparative chemical composition of capybara, cattle and pig meats. (*Source*: Torres Gaona, 1987 (quoted in FAO, 1996).)

Component	Animal species		
	Capybara	Cattle	Pig
Energy (calories/100 g)	135.0	150.0	186.0
Water (%)	63.7	71.0	68.5
Protein	22.1	21.5	18.5
Fat	4.5	6.5	11.9
Phosphorus (mg/100 g)	186.0	215.0	220.0
Iron (mg/100 g)	2.7	2.7	2.0
Thiamine (mg/100 g)	0.09	0.08	0.71
Riboflavin (mg/100 g)	0.22	0.23	0.25
Niacine (mg/100 g)	7.1	5.1	2.8

Other Products

Capybara produce some of the best leather for glove making. Known as carpincho leather ('carpincho' is the vernacular name of the capybara in Argentina, Uruguay, Paraguay and southern Brazil) it commands a very high price on world markets because it is heat resistant and stretches in only one direction allowing gloves to stretch sideways but not lengthways and thus becoming loose.

A third commercial product is oil which is extracted from the subcutaneous fat. As much as 4 litres can be obtained from an animal in good bodily condition. This oil is considered an excellent cure for asthma in Argentina, Brazil and Uruguay.

Management Systems

Many capybara are still hunted in the wild but the species is suitable for raising as a domestic animal in both extensive and intensive systems. They are easy to handle once they become tame. Average daily gains of 130 g have been achieved for animals weighing 1520 kg fed a diet of 50% elephant grass (*Pennisetum purpureum*) cut at 7 weeks of growth and 50% of a concentrate containing 14% protein. The conversion rate of feed to gain in this weight range is about 5.9:1. Daily gains are much lower at heavier weights and the conversion rate falls to about 9.0:1. On forage alone daily gains in the liveweight range of 1520 kg are only 40 g with a conversion rate of about 15.1:1.

It has been shown at several locations in South America that captive breeding and close confinement for intensive or semi-intensive production is quite feasible (Lavorenti, 1989). Disease problems might, however, be severe if husbandry is not of a high standard. Capybara are known to carry foot-and-mouth disease and seem to be particularly susceptible to brucellosis as well as to mechanically transmitted *Trypanosoma evansi*. Pens should contain only one male or there will be considerable fighting.

For extensive production (i.e. free-range grazing) enough room must be allowed for the animals to select their preferred feeds or losses from starvation might be exceptionally high. Under this type of management it is claimed that capybara are 3.5 times more efficient than cattle and bring in cash returns three times higher than cattle when the two are stocked together (González-Jiménez, 1977).

Mouse Deer

Species and Distribution

The so-called mouse deer belong to several species of *Tragulus* including *T. javanicus* the lesser Malaysian mouse deer, *T. meminna* the Indian mouse deer and *T. napa* the larger Malaysian mouse deer. One other species, *Hyemoschus aquaticus*, usually known as the water chevrotain, is also a mouse deer. Although generally called 'deer' this is really a misnomer as they possess many features that are similar to pigs. Taxonomically all mouse deer are members of the family Tragulidae. Mouse deer are indigenous to the humid lowland tropics where conventional domestic ruminants often have difficulty in surviving and producing. Their preferred habitats are dense undergrowth along rivers and in swampy areas and when threatened they use the water as an escape route. All *Tragulus* species are confined to Asia where they are found in India, Sri Lanka, Malaysia, Indo-China, parts of Indonesia (especially Java and Borneo) and the island of Palawan in the Philippines. The chevrotain is found in West and Central Africa.

Biology

Mouse deer are primitive ruminants with only three effective stomach compartments (Kay, 1987). The stomach fills almost the whole of the abdominal cavity and thus allows a large food storage capacity.

Mouse deer are among the smallestif indeed they are not the smallestof ruminants and the lesser Malaysian species weighs only 1.02.5 kg. Shoulder height is in the range 2036 cm and the head and body together measure 0.41.0 m in

length. Females are larger than males. The legs are short, the head small and the snout is pointed. Characters that they share with non-ruminants include absence of horns or antlers, tusk-like upper canines in males that grow continuously, premolars having a sharp crown, and four fully developed toes. Mouse deer are solitary, shy, nocturnal animals. Males have a chin gland that they use for marking their territories and their mates.

Mouse deer have eclectic diets. Although mainly vegetarian and eating fruits and leaves of forest trees and shrubs they also eat insects, especially ants, when they can find them. Grass is either a small part of or is absent from the diet (Dubost, 1978). They feed mostly at night and hide during the day.

Reproduction is almost continuous and seems unaffected by seasonal factors. Remating takes place within a few days of the birth of young. Gestation lasts about 56 months (a rather long time for such a small animal) and there is usually only one young per parturition. Weaning usually takes place at 23 months. Young Asian mouse deer achieve sexual maturity at 45 months whereas the chevrotain is 10 months old before it reaches this stage.

Carcase and Nutritive Characteristics

Dressed carcases contain 84% muscle and 15% bone with very small amounts of fat. The reported dressing percentage of 62% is much higher than all except the very best of other ruminants.

Management Systems

Mouse deer are avidly hunted by native people in their Asian and African distribution areas and their meat is highly prized. This, together with destruction and encroachment of agricultural land on to their preferred habitat, means that they are in considerable danger of extinction in the medium to long term.

They are, however, nervous by disposition and must always be handled with care. Asian mouse deer are regularly bred in zoos and are bred in the United States where they are a lowcost basic research 'model' for ruminants and ungulates in general. Mouse deer have also been reared successfully in small enclosures at research institutes in Gabon in West Africa and in Malaysia, and in the Philippines by one of the authors.

As potential domesticated animals they are probably best kept in a battery system of one male with two females. Pens must be covered as mouse deer are very good jumpers. The roof must, however, be high enough for the male to stand erect for copulation. In captivity they will accept a variety of feed types including bean stalks. Further research is, however, needed on nutritional requirements in more intensive husbandry systems and on housing design and health.

Muntjac

Species and Distribution.

Muntjac or barking deer belong to five species (although the taxonomy is being revised) of the genus *Muntiacus* and are among the most widespread of Asian mammals. The species are *M. muntjac* (red, Javan and Indian muntjac), *M. crinifrons* (black muntjac), *M. reevesi* (Reeves' or Chinese muntjac), *M. feae* (Fea's muntjac) and *M. rooseveltorum* (Roosevelt's muntjac). These animals, although they bark, are true deer. A peculiarity is the great divergence in chromosome numbers which vary from as low as 6 to as high as 46 depending on the species with males having different numbers from females in some species (Chapman *et al*., 1983). Hybrids between some species are known but where chromosome numbers of the parents diverge the offspring are sterile.

Muntjac are indigenous to an area that extends from east Pakistan in the west to the shores of the East China Sea. They are found in Nepal, the whole of the Malaysian peninsula and Indo-China and many islands of Indonesia. Escapes from captivity in England, where they were introduced in the late nineteenth century, have resulted in Reeves' muntjac becoming common and widespread on agricultural and forest land and even in suburban gardens.

Biology

Muntjac are small slender deer. Reeves' is the smallest species with a withers height of 4560 cm and a maximum weight of 20 kg but it usually weighs 1012 kg. The Java subspecies of *M. muntjac* is the largest type with a shoulder height of almost 60 cm and a mature weight of almost 45 kg. Males have small antlers with a main and a smaller brow tine but the pointed tip is hooked and can be used in defence. Two tusk-like canine teeth protrude from the upper jaw.

Their natural habitat is dense vegetation on hillsides at altitudes up to 3000 m. Muntjac are mainly browsing animals and select diets that are naturally high in protein (Jackson *et al*., 1977). They are active by night and day and often bark for long periods.

Breeding can take place all the year round but usually shows some seasonality. They are sexually precocious with puberty and first conception occurring as early as 6 months. Gestation lasts just under 7 months. The most usual litter size is one but twins are sometimes born. Females are remated within a few days of birth and may produce up to 20 or more young in a life span of 16 years. Males are strongly territorial and defend their areas, which are marked by secretions from frontal and suborbital glands, with determination. Adult females also inhabit their own territories.

Carcase Characteristics

The meat of muntjac has a pleasant venison-like flavour and is very lean with almost no fat.

Management Systems

Captive muntjac will eat fresh grass, lucerne hay and concentrate feeds and take readily to common root vegetables such as potatoes, carrots and parsnips. Fresh-cut browse should, however, be available as these natural concentrate selectors need diets high in protein. Muntjac are not gregarious in the wild but groups of six are kept in enclosures 40 m long by 20 m wide and 2 m high in England. Plenty of cover should be provided. It may not be possible to keep males together because of their territorial instincts and some females are also intolerant of other females. Careful attention should therefore be paid to ensure that only compatible animals are penned together.

Muntjac do not seem to suffer seriously from internal or external parasites. They are, however, susceptible to many other diseases including foot-and-mouth disease, pasteurella, rinderpest and tuberculosis.

Research on physiology, reproductive performance, feed preferences, adaptation and social structure and temperament in relation to domestic breeding should pay handsome dividends in the process of domestication and diversification of production systems.

Iguanas and Other Reptiles

Species and Distribution

Many reptiles have been important contributors to human welfare for millennia. They provide meat, skins and other products and are often a source of supplementary income when they are shot, trapped or hunted with dogs over much of Asia, Africa and South America. The range of species is large and varies from tiny agamids to enormous crocodiles.

Several species of reptile seem suitable for domestication or at least for commercial production. Most attention in the recent past has been given to the iguanas of South America. These are herbivorous species that feed mainly on leaves, flowers and fruits and seem more suitable than some of the carnivorous reptiles that are seen offered for sale in some markets elsewhere. The species about which most is known is the green iguana *Iguana iguana*. It is likely that its close relatives the black or spiny-tailed iguanas, including *Ctenosaura similis*, *C. acanthura*, *C.*

hemilopha and *C. pectinata*, have similar characteristics. The common South American name for the black iguanas is 'gallina de palo' or 'chicken of the trees'. Green iguanas are found in their preferred tropical lowland forests usually close to water in Central and northern South America and several Caribbean islands. Spiny-tailed iguanas have a more restricted distribution in Central America in drier open woodland areas. One other genus which may prove suitable as microlivestock is *Tupinambis* which includes *T. rufescens* and *T. teguixen*, both of which species are known as tegus. Tegu, like crocodiles, produces a valuable leather and, although they are most common in Argentina and Paraguay, they are found as far north as Colombia as well as on the island of Trinidad.

Biology

Green iguanas grow to a length of as much as 2 m of which about half is the long whip-like tail. Mature animals weight up to 4 kg. Black iguanas are shorter than green iguanas but have shorter tails, are of more solid build and weigh about 3 kg when adult. As with most lizards colour is related to age, sex and reproductive status.

Green iguanas, as most cold-blooded creatures, are lethargic when cold but are more alert and active at the height of the hottest part of the day. Their social structure is complex and their breeding is seasonal (van Devender, 1982). Sexual maturity is reached at 23 years when one clutch of 1085 eggs (average probably about 35) is laid each year; eggs are also popular as human food. Black iguanas spend more time on the ground than the green types but are not averse to climbing trees. They live in holes in trees or burrows which may have several entrances and be 2 m or more long. Several females may share a burrow complex in which each has its own nest chamber. A single clutch of 2090 eggs is laid per year but as the eggs are smaller than those of the green iguana they are less popular as human food.

Iguanas have a specialized digestive system in which food breakdown is done by bacteria in an enlarged fermentation chamber. Food is converted to meat as effectively as it is in cattle but the process takes relatively longer. Both species are mainly vegetarian but black iguanas also feed on insects and small vertebrates. Green iguanas are able to convert the vegetation of tall trees to human food much more effectively than any other potential food species.

Carcase Characteristics

Iguana meat is much sought after in most of Latin America and commands a higher price than beef, pork, poultry or fish. As the value of one animal usually greatly exceeds the daily wage of a rural worker it is hardly surprising that they are intensively hunted.

Management Systems

The traditional system of exploiting reptiles is by hunting them in the wild. In South America, however, as in Africa, some species have been hunted so ruthlessly that they are now endangered in many areas. African crocodiles, for example *Crocodylus niloticus*, have been hunted to the verge of extinction since they were regarded as vermin even as recently as the mid-1960s (Wilson, 1978). Crocodiles are, however, rather easy to rear in captivity (Fig. 17.8) if a proportion of their eggs is taken from the wild and they produce marketable skins for such items as handbags and shoes at as young an age as 4 years. In much of South America iguanas are the preferred game animal and are hunted regardless of sex and reproductive status so that egg-carrying

Fig. 17.8
Crocodiles reared from eggs taken from the wild
in southern Ethiopia.

females are taken to the detriment of the population as a whole.

Captive breeding or domestication of iguanas has several advantages over indiscriminate and uncontrolled hunting including the much higher survival rate of young (more than 90% of young wild iguanas may be taken by predators in the first few months of life) and the possibility of restocking wild populations.

An iguana farming project in Panama and Costa Rica which raised more than 10 000 green iguanas in its first 5 years of operation may serve as an example that could lead to more widespread commercial farming of iguanas. Pens comprise sheet metal sunk 30 cm into the ground and each enclosure has plenty of shelter made from bamboo and other vegetation. These protect the lizards from predators, are raised from the ground and food is provided underneath. Some 2060 young iguanas can be kept on 10 m2. Artificial nest sites are provided as tunnels leading to a nest chamber which results in almost 100% hatching (Werner & Miller, 1984).

In the system described in the previous paragraph a mixture of broken rice, meat meal, fish meal, various fruits and leaves and flowers are fed. Young iguanas take about 3 years to reach marketable size. An alternative system is to rear young stock to about 10 months and then release them in trees nearby. If they are fed some supplementary food here they tend to stay in the vicinity and can be harvested when they reach a suitable size.

Snails.

Species and Distribution

Snails are important as human food in some parts of the tropics and especially in West Africa where, as in parts of Ghana, they may be the main source of animal protein (Beckett, 1994). Edible species belong to the family Achatinidae (Hodasi, 1984). Commonly known in English as giant African snails, two genera are farmed or gathered for human consumption, each with three species.

Achatina is the most sought-after genus. The largest species is *A. achatina*, which is distributed along the West African coast from Guinea to Cameroon. *A. balleata* is somewhat smaller and has a less conspicuously marked shell. An isolated population of this species occurs in Sierra Leone but it is found elsewhere in Cameroon, Equatorial Guinea, Gabon, Congo, Democratic Republic of Congo and Angola. *A. monochromatien* is similar to *A. balleata* but is limited to southern Benin. A species originally indigenous to the Tanzanian and Kenyan coasts, *A. fulica*, is not eaten there but has spread with commerce to Southeast Asia and the Pacific islands, where it has become a pest in some areas.

Three species of *Archachatina* are also from West Africa. These are smaller than *Achatina* and less popular as human food. The most widespread is *A. marginata*, distributed from Nigeria to the Democratic Republic of Congo. The other species have more restricted distribution, *A. ventricosa* occurring from Sierra Leone to the Côte d'Ivoire and *A. degneri* from Ghana to Benin.

Biology

Snails are hermaphrodites but cross-fertilization is the rule. *Achatina achatina* is the most precocious *Achatina* species, becoming sexually mature and first laying eggs at 711 months. Eggs are laid 820 days after mating but a single mating results in several clutches over a period of months. Egg size and number vary among clutches but *Achatina* lay 140180 small eggs per clutch while *Archachatina* lay 612 larger ones. Egg-laying to hatching takes 67 weeks but hatching within a clutch is prolonged. Hatching in the wild is about 50% of eggs laid but this can be improved under controlled conditions (for example 77% when kept on a damp cloth).

Archachatina marginata hatchlings weigh about 2.1 g, and gain about 0.85 g per week to reach about 35 g at 40 weeks. *Achatina achatina* has a mature body weight in the range 200350 g at 3 years.

Snails are omnivorous feeders and eat many wild and cultivated plants. They are thus possible

pests. Many small species feed on decomposing material and detritus as well as green stuff. In spite of eclectic dietary tastes snails may not be very efficient users of organic waste under controlled conditions as they can be very selective feeders.

The natural habitat is damp ground with undergrowth. During dry spells free-living snails conserve water by sealing the shell opening with an epiphragm and aestivate by reducing mobility, reproductive behaviour and growth. Under controlled conditions, high humidity is needed to ensure optimum performance.

Most African snails at markets are wild caught and there are several levels in the marketing chain to the major cities (Fig. 17.9). Snails pro-

Fig. 17.9
Snails on sale at a local market in Lomé, Togo (note also grilled grass cutters in basin at centre of photo).

vide subsistence food as well as income. Urban consumers pay twice as much for snails as for red meat, the price in Abidjan in Côte d'Ivoire (where the annual consumption is estimated at 1000 t per year), being about US$2 per kg in 1986, or a total value of US$2 m for one city alone.

Carcase and Nutritive Characteristics

About 38% of total weight, representing the 'foot', is edible. The shell is equivalent to 26%, viscera 16%, and blood and slime 18% of total weight. Calcium, magnesium, potassium and iron are major minerals in the foot. Calcium amounts to about 86% of shell weight. Protein in the edible portion (Table 17.6) is higher than in ruminants and similar to that of giant cane rats and poultry. Energy content of the dry matter is about 80 cals/100 g which is much less than the 229 cals/100 g of poultry.

Management Systems

Most snails currently eaten at home or sold are gathered in the wild. In view of general estimates of the size of the market there must be some concern for the long-term survival of the snails.

Extensive open or intensive closed or semi-closed systems have been proved feasible in both Europe and Africa. Extensive systems are a natural development of gathering. Snails are

Table 17.6 Proximate composition (%) of raw and processed snail meat. (*Source*: Aboua & Boka, 1996.)

Component	Processing method					
	Raw	Fried	Smoked	Boiled		
				Fresh	Frozen	Canned
Moisture	43.50	5.50	7.80	28.00	25.50	31.00
Proteina	67.30	70.90	73.60	70.20	69.00	70.50
Lipidsa	4.62	8.15	3.69	3.75	4.47	4.58

Asha	6.77	6.35	6.29	5.89	5.11	6.68

a Of dry matter.

usually kept in enclosures until after breeding and then fattened on a variety of sown crops including turnips, burdock (*Arctium lappa*), plantain (*Plantago lanceolata*) and lettuce, chicory and Jerusalem artichoke. In Nigeria snails showed a preference for succulent feeds such as lettuce leaves, pawpaw leaves and pawpaws and bananas (Imevbore & Ajayi, 1994). Fattened snails are sold in West Africa in the dry season when prices are high. Young are returned to the wild to grow out or kept in an enclosed intensive system. Intensive systems are more difficult to manage and must take account of location and market factors as well as possible repercussions arising from the nuisance of their smell.

Constraints to Increased Productivity and Opportunities for Development

The major problems facing increased use of nonconventional microlivestock are conventional attitudes to change and to the unknown. The types of livestock husbandry discussed in this chapter are already accepted by many small-scale and poor farmers and others who may be faced with little choice in the activities they are able to undertake. A small sample of the possibilities for managing and reaping the benefit of a wide range of types and species of 'livestock' has been discussed. There are almost limitless opportunities for developing other species. Research on and development of these opportunities will support more effective contribution of livestock in the tropics to sustainable produc-tion, environmental conservation and the maintenance or enhancement of biodiversity.

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PART III
ANIMAL PRODUCTS

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18 Milk and Milk Products

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Milk Production and Consumption in the Tropics.

The average amount of milk produced per person per year in developing tropical countries is 37 litres compared with 300 litres in developed countries (FAO, 1995). In the developing world consumption varies widely between and within countries as a result of variations in income, food customs, livestock ownership and nutritional knowledge. For example, milk is often too expensive for poorer city people to buy, but the rural poor may use milk and milk products from their livestock as a major source of food.

In the two decades preceding 1985 consumption of milk in developing countries was increasing at 3.6% per annum, compared with an increase in production of 2.8%. This led to a rapid growth in milk imports, from US$540 billion (Phelan & Henriksen, 1995). From 1985 production has increased by 3.5% annually, sufficient to meet a similar annual increase in consumption (FAO, 1995). In the rapidly expanding economies of Eastern Asia, production and consumption are increasing at 5% annually. This growth has meant that the dairy industries in tropical countries with no tradition of dairying, such as Thailand and Malaysia, are becoming substantial milk producers, along with the established industries in countries such as India, Kenya, northern Australia and Zimbabwe.

Where the local supply falls short of demand, supplies for the cities are often manufactured from imported ingredients, provided by developed nations at a subsidized price. In the Philippines for example, despite a threefold increase in production from 1970 to 1994, 99% of the milk consumed is still imported (Matias, 1995). Imported skim-milk powder and butter oil are recombined with water to make reconstituted milk, sweetened condensed milk, evaporated milk, ice-cream and milk drinks. In 1993, 27% of world trade in skim-milk powder was imports by Southeast Asia for the recombination of milk products (Griffin, 1995).

Fresh liquid milk is not the major milk product in many tropical areas. In traditional milk-drinking societies, milk has always been converted to more stable products like fermented and concentrated milks and ghee, that retain their feed value for a longer period without cooling.

Milk and milk products have not been traditionally accepted by consumers in many tropical countries, particularly in Southeast Asia. For example, in the Philippines it is still not seen as an indispensable food. Others like the Han Chinese have strong cultural inhibitions to milk consumption. On the other hand, milk is very well accepted in India, much of Africa, the Americas and the West Indies. Milk is probably India's most valuable food, with even the lowest income groups buying a surprising quantity. Some pastoral tribes in Africa and Western Asia consume very large quantities of milk and milk products and survive on milk as their only protein food for periods of the year.

An intolerance to lactose, caused by a deficiency of lactase in the digestive system, has been reported in racial groups with no tradition of milk consumption. The condition can be congenital and serious, leading to death in some cases unless lactose is withdrawn. However, the majority of cases are due to an acquired intolerance resulting from a low milk consumption and hence no need for lactase activity after weaning (Cobiac, 1994). In some Asian communities up to 90% of the people may suffer from this form of lactose intolerance. It is rarely dangerous and sufferers can often safely use small amounts of milk (British Nutrition Foundation and Royal College of Physicians, 1984) and acquire a tolerance. The traditional fermented milk products of the tropics contain little or no lactose (after its conversion to lactic acid) so they can be eaten by lactose-intolerant people, unless their lactose content has been raised by adding skim-milk powder.

Milk Producers in the Tropics

Milk is produced by a very mixed cross-section of farmers in the tropics. It is mostly produced from livestock kept primarily for other purposes. There has been some growth in specialist dairy farms, but still the major proportion is produced from millions of small traditional subsistence farms, pastoral herds and flocks and beef-producing ranches. The intensive small cultivators of the wetter tropics keep cattle and buffaloes for draught work in crops, to produce dung that is used either as a fuel and/or fertilizer and to utilize crop by-product feeds. Goats and/or sheep may also be kept as a source of meat for the family. Milk from all of these animals is produced at little or no cost. In pastoral herds in the drier regions of Africa and Western Asia, sheep, goats, camels, and cattle provide milk for the herding families, often for periods their only food source. In Western Asia and North Africa, in particular, seasonal surpluses of milk are made into longer-life cheeses for local consumption or for sale in markets. The majority of milk produced in lowland tropical South America comes from beef herds in which selected beef or dual-purpose cows are milked once or twice a day in the presence of their calves.

There are now a significant number of large specialized dairy farms in most tropical countries supplying milk to the cities. These farms are sometimes located in regions most suited to dairying, like medium to high altitude areas where more productive livestock can be kept. In addition, some smallholders are steadily changing to specialized dairying as markets become more secure and they are provided with access to advice, concentrate feedstuffs, artificial insemination (AI) and veterinary services. For example, there are now about 16000 dairy farms in Thailand producing an average of 8400 litres of milk for sale annually, compared with just a few thousand 10 years ago. There are also approximately 30 medium-sized farms with 50500 cows, and one very large dairy producer with two farms, each of several thousand cows. The rapid growth in the dairy industry in Thailand for the period 199296 is shown in Table 18.1. It is anticipated there will be a 15% annual growth in demand for milk products in Thailand over the next 5-year period, and up to 50% for some products such as drinking yoghurt.

Table 18.1 Milk production and consumption trends in Thailand for the period 199296. (*Source*: ASEAN Focus Group, 1995.)

Year	No. of milking cows (000 head)	Raw milk produced (million litres)	Total milk consumption (million litres)	(litres/person)
1992	98	180	720	12.5
1993	111	206	755	12.9
1994	130	265	830	14.0
1995	146	308	955	16.0
1996 (projected)	165	358	1098	18.1

The rapid growth of the economies of Southeast Asia should ensure continuing growth of the dairy industry. In Central and South America there are also examples of renewed growth in the dairy industry. The Mercosul economic agreement between Brazil, Argentina, Paraguay and Uruguay has stimulated production in those countries. Milk production in Costa Rica is 530 million litres annually, and is expanding at 5% each year. Mexico is now one of the largest consumers of milk products exported from the United States, but has also developed a large dairy industry, based on feedlot dairies, that provides 54% of total consumption. However, throughout Central and South America over 50% of milk production is from rain-fed, mixed farming systems in the humid and sub-humid zones (Seré & Steinfeld, 1996).

Livestock Producing Milk in the Tropics

Cattle provide 66% of tropical milk, with buffaloes supplying 25% and goats, sheep and camels supplying the rest (FAO, 1995) as shown in Table 18.2. The majority of milking stock are not specialized dairy animals, except in the case of the larger dairy farms, and approximately 92% of milk is produced in mixed farming enterprises (Seré & Steinfeld, 1996). For example, during the annual wet season in Brazil a substantial part of the milk sales come from beef herds, providing these farmers with a cash flow, but effectively reducing the price received by specialist milk producers.

Indigenous, mainly zebu, cows are milked on the majority of smaller traditional farms and wherever the environment is harsh, but crossbred

Table 18.2 Annual milk production for 1994 in regions of the world, and the contribution of individual milk-producing species. (*Sources*: FAO, 1995; Wilson, 1984.)

Livestock and milk production	Region						
	World	North America	Central and South America	Europe	Africa	Asia	Oceania (Pacific)
Cattle							
No. (000 head)	1 288 124	113 294	329 716	107 158	192 180	410 118	34 049
Milk production (000 t)	458 645	77 392	46 863	152 550	15 197	67 129	16 783
Water buffaloes							
No. (000 head)	148 798		1 445	133	3 200	143 640	
Milk production (000 t)	48 190			140	1 580	46 470	
Goats							
No. (000 head)	609 488	2 037	35 726	14 809	176 089	373 005	1 007
Milk production (000 t)	10 480		341	1 633	2 003	6 135	
Sheep							
No. (000 head)	1 086 661	10 291	101 292	130 692	208 845	340 102	182 758
Milk production (000 t)	7 981		34	2 608	1 542	3 682	
Camels							
No. (000 head)	18 831				13 815	4 761	
Milk production (000	>730	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

t)							
Total milk production (000 t)	525 296	77 392	47 238	156 931	20 322	123 416	16 783

Stock numbers listed are all types of livestock, not just milking animals.
n.a. = not available.

cows (temperate × zebu breeds) are being used increasingly for milk production on small farms as management and husbandry gradually improve. For example, in Southeast Asia there has been a substantial growth in the use of Sahiwal × Holstein-Friesian cows (Fig. 18.1). The 50:50 gene mix has proved superior to Holstein-Friesians in harsh tropical environments, and a 25:75 gene mix superior in subtropical or less extreme environments (Tierney & Reason, 1986). Purebred temperate cows are mostly found where husbandry is good and the adverse effects of climate are reduced by altitude or specialized management.

Water buffaloes are the main dairy animals for small farmers in India, Pakistan and other countries in South Asia. Goats' milk is important to the pastoralists of Western Asia, and in North, East and West Africa. Sheep are milk suppliers for pastoralists and small farmers in North and Northeast Africa, some regions of India and drier areas of Iran and Iraq. Likewise camels provide the only major source of milk for some pastoralists in Africa in the arid areas where other livestock cannot survive.

Fig. 18.1
One of the major developments since the late 1970s has been the breeding of productive, tropically adapted dairy cattle. This cow, containing 50% of genes from the Holstein Friesian and 50% from the Sahiwal, is representative of many breeding programmes.

Possibilities for Dairy Development in the Tropics

With most tropical milk being produced in small amounts from multi-purpose livestock, prospects for increasing milk yields rapidly are not very hopeful. Improvements are being made in mixed farming systems, but very slowly. More rapid progress is being made in countries such as Thailand where the development of a specialized dairy industry is being encouraged.

Support services like technical advice, credit facilities, organized markets, seed and fertilizer supplies and suitable equipment are not available to many tropical farmers. Overwhelming problems such as lack of education and little cash prevent small farmers from increasing their production rapidly. As a result, many tropical countries have encouraged large intensive dairy farms to be set up in order to provide more milk quickly to meet the increasing demand from urban areas. Generally these farms produce a high-priced product and import much of their technology.

Most governments in developing tropical countries are encouraging dairy development for several good reasons: to meet increasing local demand for milk, to improve the nutrition of the urban poor, to supplement the incomes of the rural poor, to reduce reliance on imported goods and to encourage rural development and services. In most countries that means developing a few specialized farms, while encouraging at the same time increased milk production on small farms by providing them with access to regular markets and the support services they need.

Co-operatives

In many tropical countries farmer co-operatives are being used to develop the dairy industry. These co-operatives have already achieved success in countries such as India, Thailand and Brazil, through assistance in planning, marketing, extension and health services. Co-operatives enable small farmers to develop production, and have been instrumental in the recent growth in milk production of over 5% annually in such diverse countries as Thailand, India, Brazil and Argentina. A key feature of co-operatives is the more consistent pricing of milk for farmers; this has been effective in South America in reducing the rapid movements in and out of the dairy industry, depending on the relative prices of milk and meat at any one time.

The Role of Milk in Improving Nutrition

In most developing countries, poor families are undernourished on account of low income and/or an inability to produce enough food for themselves. They survive on high-starch, low-protein foods like rice, maize, sweet potatoes, yams, cassava, etc. Adults in these families are often deficient in energy, while pregnant and nursing women are also short of protein and calcium. Children are most badly affected, because of their high requirements for energy, protein, calcium and other minerals and vitamins. In these countries, milk could greatly improve people's health. A small daily amount of milk (100200 ml) per child would improve infant, toddler and school children's nutrition, decreasing mortality from deficiency diseases and reducing the impaired physical and mental growth they cause.

The nutrients in milk of most importance to humans are protein, calcium, potassium, phosphorus, other trace elements, vitamin A, riboflavin and thiamine. For example, 500 ml of cows' milk (4.5% fat) will provide 25% of the calories, 40% of the protein, 70% of the calcium and riboflavin, and 30% of the vitamin A and thiamine requirements of a 5-year-old child (Kon, 1972). Milk is the most complete, single food and can be the sole food source if necessary for a period. For example, it was found that the nomadic M'Bororo of West Africa lived exclusively on milk for months (Kon, 1972).

Milk is a fairly low-calorie food so it is a relatively expensive source of energy. However, tropical milks generally have a higher fat content than temperate-zone cows' milk (Table 18.3).

Table 18.3 Average composition of milk from important tropical species. (*Sources*: various sources including Kon, 1972; Warner, 1978; Wilson, 1984.)

Species	Average composition											
	Fat (%)	Solids-not-fat (%)	Protein (%)	Lactose (%)	Calcium (%)	Vitamin A (µg/g fat)	Carotenoids (µg/g fat)	Vitamin A activity (µg/100 g)	Vitamin D (IU/100 g)	Riboflavin (µg/100 g)	Thiamine (µg/100 g)	Vitamin C (mg/100 g)
Temperate- type cow Friesian	3.5	8.5	3.3	4.6	0.12	8	7.0	42	1.8	150	40	2.0
Temperate- type cow Jersey or Guernsey	4.6	9.0	3.6	4.9	0.13	6	16.0	65	2.3	200	40	2.0
Zebu-type cow	5.0	8.5	3.2	4.6	0.13		Pale yellow fat					
Buffalo	7.5	9.0	3.8	4.9	0.19	8	Trace	67		100	50	2.5
Goat	4.0	8.7	3.4	4.2	0.13	8	Trace	40	2.3	120	50	2.0
Ewe	7.5	11.5	6.0	4.4	0.20	8	0.4	67		500	70	3.0
Camel	4.2	9.0	3.8	5.0			Unlikely (white fat)	60				6.0
Mare	1.2	8.5	2.2	6.3	0.09	8	3.0	15		20	30	10.0
Ass	1.5	8.6	2.0	6.2	0.08	Fat is orange/ yellow				30	60	10.0
Human	4.0	9.0	1.3	6.8	0.03	10	4.0	53	1.4	40	17	4.0

Missing figures mean information is unavailable or unreliable.

Many tropical people have no other source of animal fat, so high-fat tropical milk is a very important part of their diet. Milk fat is very easily digested and is necessary for calcium absorption.

Milk is an excellent source of protein, containing all the essential amino acids required by humans, the mix being ideal for supplementing the amino acid in cereal proteins. Skim-milk powder is now accepted as the best protein supplement for undernourished children. Frequently milk is the only source of animal protein in the diet, 500 ml of cows' milk providing at least 16 g of protein. Milk and dairy products are outstanding sources of calcium and are frequently the only source for people traditionally using milk, 500 ml of temperate-type cows' milk provides 650 mg of calcium. Milk is also a good source of phosphorus, potassium and many trace minerals. Whole milk is a valuable source of vitamin A when used fresh, or as carefully made high-fat milk products. Milk is also an important source of riboflavin, and a low but significant source of thiamine for people living on rice-based diets500 ml of temperate-type cows' milk provides 1000 µg of riboflavin and 200 µg of thiamine. Other B vitamins are also present in measurable quantities. Milk is not usually an important source of vitamin C, except for camels' milk which has a high content and provides possibly the only source for arid land pastoralists at certain times of the year.

Full-fat milk is particularly important for babies less than 1 year old if breast milk is not available. Children are often more undernourished after being weaned from breast milk on to low-quality adult diets, so that milk is a very important weaning food. The most widely used formula for weaned children is precooked cereal flour/protein concentrate/vitamin/mineral mix.

Milk supplies in most countries are usually unevenly distributed, being scarce where they are needed most. The rich use much more than the poor, with whole milk being too expensive for average income earners in most developing countries, and adults traditionally using most of the scarce milk supply in tea or coffee rather than giving it to their children. Methods are required to provide milk for the poor; these could be through the use of external aid or by the provision of cheap forms of milk, such as unpackaged, toned and filled milk.

Milk Composition and Properties

Milk is a complex mixture of water, fats, proteins, lactose, minerals, vitamins and enzymes together with some cells. The milk fat, containing around 66 different fatty acids, is emulsified and dispersed in the water in small globules, each globule surrounded by a membrane to prevent fusion. Milk with a higher fat content generally has larger globules. Fat gives milk its characteristic smoothness, flavour and colour. Eighty per cent of milk protein is casein which, in combination with calcium and phosphorus, forms a curd when rennet, acid or alcohol are added to milk. The other important milk proteins, lactalbumins and lactoglobulins, are soluble, so drain off in the whey when a curd is formed. Lactose is the least variable component in milk. Fermentation of lactose by bacteria results in the production of lactic acid and souring, the basis of many cultured dairy products. Together with protein and minerals, lactose makes up the solid-not-fat (SNF) content of milk. The important minerals and vitamins in milk have already been mentioned.

Milk varies in colour from bluish white to deep yellow, according to the riboflavin and carotene content. It has a slightly sweet flavour and smell, but easily acquires unpleasant odours and taints. Acidity is normally in the range of pH 6.56.8, but uncooled milk quickly becomes more acid. Fat globule size is very variable between and within milk-producing species.

Milk from Different Species

The same nutrients are present in the milk of all species, but in different proportions. Composition differs between species, between breeds and between individuals, and is altered by the plane of nutrition, the age of the animal, the stage of lactation and the amount of milk produced. Table 18.3 shows the average composition of milk from a number of species. Less developed and multi-purpose stock, such as the indigenous tropical cattle breeds, produce a low volume of milk that is usually richer in fat and total solids than the milk of specialized temperate cattle breeds.

Human milk is low in protein and minerals, while the lactose and fat content are relatively high, resulting in a similar energy content to cows' milk. Human milk fat does not contain short-chain fatty acids like ruminant milk, and has less casein and more soluble proteins. The vitamin content of human milk varies greatly with diet, especially the vitamin C, riboflavin and thiamine contents.

Cattle, like all other ruminants, manufacture protein from other nitrogen sources and produce vitamin C and the B vitamins in their rumens. The fat, protein and SNF percentages in milk vary widely between breeds and with diet. Milk from indigenous tropical cattle and Channel Island breeds is higher in fat and total solids than milk from Friesian/Holsteins. Fat globule size varies with fat content, but the globules in all undisturbed cows' milk rise to the top and cluster together as a cream layer. Cattle breeds differ in their ability to convert carotene (obtainable from green feeds) into vitamin A. Jerseys, for example, are less efficient than Friesians so their milk contains more carotene, giving the milk fat a strong yellow colour. Zebu milk contains less carotene than the milk of Jerseys, so it is a pale yellow colour.

Buffalo milk is richer than cows' milk, containing twice the fat (averaging 7%) and a very high total solids content. It is often preferred by people with access to both types of milk. Buffalo milk contains more casein, with a lower solubility and different structure to cows' milk casein. It also contains more calcium and phosphorus, less sodium and chlorine, less riboflavin and more vitamins C and A. Buffalo milk fat is pure white, as all the feed carotene is converted into vitamin A. This characteristic can be used to distinguish buffalo milk from cows' milk. Buffalo milk is greyish white and has a distinct opaque appearance when spread thinly over glass. The fat globules in buffalo milk are larger than those in zebu cows' milk, and the curd is slightly harder. It is not as good as cows' milk for making hard Cheddar cheeses, but is considered superior for the production of fermented milk products, ghee (*semna*) and soft cheeses. Buffalo milk must be adjusted for infant feeding by adding phosphate and citrate, and by decreasing the curd tension by heating. It is now being successfully processed in many ways in India (Ganguli, 1979). The richness of buffalo milk also makes it ideal for toning in order to extend its volume. This process is discussed later.

Goats' milk is fairly similar to cows' milk in its major constituents. Like tropical cows, tropical goats produce milk with higher fat and solid contents than temperate types. The average milk fat globule size is small so that fat does not tend to rise on standing and it is difficult to separate the fat for making cream, butter or ghee. The fat also contains more short-chain fatty acids than cows' milk. Combined with small fat globule size, the low curd tension of goats' milk makes it easy to digest. Most of the feed carotene is converted to vitamin A, so the fat is very white. Goats' milk has more niacin, less vitamin B12 and slightly higher phosphorus, potassium and chlorine contents than cows' milk. The proteins differ from cows' milk in amino acid composition and casein structure.

Sheep's milk has a very high solids content, containing more protein and calcium in particular, and more fat, riboflavin, niacin and vitamin C than cows' milk. Because of its high protein and fat percentage, sheep's milk is prized for cheese-making and is very useful for yoghurt, butter and ghee. There is little information on the other properties of sheep's milk.

Camel milk is generally similar to cows' and goats' milk, but detailed information is scanty. The solids and water contents can vary widely with water availability. One study showed that when water is scarce the water content of milk actually rises, probably to protect the calf from dehydration. Camels' milk also has a high vitamin C content (6 mg/100 ml) which is very important to pastoralists with no access to green vegetables and fresh fruits. The fat is in very small, micelle-like globules, apparently bound to the proteins, making it difficult to process into good butter, ghee or cheese. The fat is very white so is unlikely to contain carotene. The vitamin A content is up to 7.14 mg/100 ml. Camel milk appears to have a low calcium content but reasonable amounts of phosphorus and iron.

Horse and ass milk are sometimes used. Mares' milk is thought to be very suitable for infant feeding as it is most like human milk in composition.

Factors That Change Milk Composition and Properties

Some milk constituents, like lactose and minerals, are always present in much the same proportions, while others (particularly fat) vary widely from day to day, even from milking to milking. The main factor altering milk composition is milk yield at each milking, changing the percentage of components by dilution or concentration.

Nutrition has a major effect on milk composition. Good feeding, particularly a high-energy intake, tends to stimulate milk yield and the SNF percentage and to lower the fat percentage by dilution. Underfeeding has the opposite effect. Milk fat content tends to be reduced by feeding finely ground or pelleted forage, large quantities of maize grain or fat, flaked or heated grains and starches, and lush, low-fibre-content crops. Solids-not-fat is reduced by low-energy diets, falling body condition and a low dietary protein intake (less than 12% crude protein (CP)). The milk contents of vitamins A, D and E all depend on the intake of their dietary precursors and are all at their highest when animals eat green leafy pastures or crops. The mineral content of milk, with the exception of iron and iodine, changes little with dietary content.

Animal size and body condition affect the yield and composition of milk. Within breeds, large mature animals in good body condition tend to give the most milk. Animals in better body condition produce milk with higher fat and SNF percentages.

Stage of lactation has an important bearing on milk composition. Colostrum differs greatly from normal milk, as shown in Table 18.4. It has a very high solids content (especially globulins, minerals and vitamin A), is bright yellow in colour with a strong odour and often a bitter taste. In temperate-type cows, milk fat and SNF percentages tend to be high in the early weeks of lactation, dropping by the third month then rising again as milk yield gradually declines.

Milking practices can also affect milk composition. The first-drawn milk has a low fat percentage (only 12% in temperate cows' milk) and the last milk drawn from the udder has a high fat content (79%) due to the uneven distribution of fat globules. For example, Jones (1972) demonstrated that the practice of hand-milking Baluchi ewes, then allowing the lambs to finish off, gave most of the fat to the lambs (3.9% in the first drawn compared with 7.2% in the last) and less for cheese-making.

Adverse climatic conditions have a substantial effect on both milk yield and composition, often through effects on feed intake by the cow. Cows will reduce their grazing activity in very wet weather. In the case of housed cattle intake may be restricted by either the high (over 80%) moisture content of grasses or the difficulties in harvesting sufficient grass for transport to the cows. With high environmental temperatures (over 30°C) cows also reduce grazing effort and intake (Cowan *et al*., 1993). Thus low protein and lac-

Table 18.4 Average composition of cow colostrum and normal cows' milk 23 weeks after calving. (*Source*: Foley *et al*., 1972.)

Constituent	Colostrum (%)	Normal milk (%)
Total solids	28.30	12.86
Total protein	21.32	3.34
Albumin	1.50	0.54
Casein	4.76	2.80

Globulin	15.06	
Fat	0.1512.00	4.00
Lactose	2.50	4.80
Ash	1.58	0.72

tose contents in milk are often associated with excessively hot or wet weather. European-type dairy cattle have particular difficulty in hot, humid weather, and intake can be depressed for long periods. An initial increase in milk fat associated with the reduced volume of milk may be followed by a decrease once body fat reserves become depleted. In some areas persistent, strong winds may also reduce grazing effort by cows. Sick animals produce milk with low solids but with high sodium and chlorine content, which is generally discarded for safety and its salty taste.

Milk Quality.

Milk starts to deteriorate as soon as it leaves the udder, as bacteria grow and flavours and odours are absorbed from the atmosphere and utensils. In the early stages of tropical dairy development milk quality is an important problem, with stock being milked in the open into unsterilized utensils, resulting in milk with a high bacterial content. Without cooling, the milk spoils quickly in hot humid conditions.

Common Quality Problems

Microorganisms in milk may cause problems by spoiling the milk (changing its flavour, smell and appearance) and by being pathogenic to man. Freshly drawn milk contains few bacteria (from 500 to 1000 bacteria per ml). The first few squirts of milk contain the most bacteria (from the streak canal and exposed teat ends), so this should be discarded. There are many ways for bacteria to enter milk after it leaves the udderfrom soil and manure on the teats, from the milkers' hands and clothes, from the milking shed, from feeds given at milking time, from milking machines, pipelines and utensils and from the cleaning water.

In the past, milk was responsible for transmitting many diseases to man from the milking stock, from milk handlers or the cleaning water. Diseases that have been transmitted to man via milk include tuberculosis, typhoid, cholera, diphtheria, brucellosis, melioidosis, salmonellosis, Q fever, streptococcal infections and coliform enteritis (McCoy, 1966). Improved sanitation and heat treating milk has reduced disease outbreaks from milk in most countries, but the risk still exists where milk and dairy products are consumed untreated and water supplies are polluted.

Under high atmospheric temperature bacteria will multiply very quickly. The effect of temperature on bacterial numbers is shown in Table 7.29. Freshly drawn milk appears to have some bacterial property which helps to preserve it for up to 2 hours for cows' milk or up to 4 hours for buffalo milk during which time any bacteria entering milk have a lag phase before reproducing rapidly. Milk quality is therefore held for that short time but milk must be treated in some way (by cooling, heating, adding preservatives or converting to more stable products) if it is to last longer.

Milk easily absorbs taints and off flavours from within the udder, during milking, and in storage. Within the cow, milk from sick or late lactation cows will develop a salty taste from the higher sodium chloride content of the milk. Cows with even mild ketosis produce milk with a strong 'cowy' flavour. Many strong external smells enter milk in the udder by being breathed in or burped up and on to the breath, entering the blood and crossing to the milk. Strong feed odours and flavours like those from brassica crops, fish meal, citrus and pineapple pulps and silage quickly taint milk within the cow. The odour of poorly ventilated housing and strong-smelling bedding will also be transferred to milk within the cow, as will the strong buck goat smell to doe milk.

Milk will also absorb any strong taints and odours from the atmosphere and utensils. Strong feed odours, dairy disinfectants, manure and mud odours, and fumes from smoke, engine exhausts, paint and kerosene, for example, can be tasted in milk if it is not covered and protected from them. Cooling and regular stirring help to decrease and drive off some of these strong flavours.

Milk can also undergo biochemical changes that alter its flavour. The fatty acids in milk will oxidize in the presence of copper and iron (present in utensils or cleaning water) and when exposed to the sun. Well-chilled milk is more prone to oxidizing as is milk produced from concentrate feeds and from early lactation cows. The flavour is commonly described as cardboardy, metallic, oily or tallowy. Milk fat can also become rancid if the globule membrane is destroyed, allowing the natural milk enzyme lipase, to lipolyse the fat. Agitation, freezing, adding warm milk to cool, all increase the possibility of lipolysis. When milk is overheated by boiling or sterilizing it can develop a cooked taste.

Another important quality problem is the possible presence of contaminants and residues in milk. Many pesticides, antibiotics, drugs, heavy metals and radioactive contaminants can be excreted from the animal's body in milk. Of the pesticides used in animal production and cropping, the chlorinated hydrocarbons, like DDT and dieldrin, are absorbed into the body fats and continue to be excreted in milk long after they have been withdrawn from use. Organophosphates are apparently not excreted in milk (Schmidt, 1971). Almost any antibiotic used on a milking animal will be excreted in her milk. Even when one mastitic quarter is infused with an antibiotic, milk from all quarters will become contaminated via the blood supply. Small traces of antibiotics in milk can be dangerous to humans who are allergic to penicillin, and fermented dairy products cannot be made from the milk as the culture will be inhibited. Many other drugs used on livestock, including some anthelmintics and sulphur drugs, will appear in the milk (Rasmussen, 1966).

Producing Good-Quality Farm Milk

As milk becomes available for public sale, some government authority or milk board usually takes responsibility for setting standards and supervising milk quality. The methods used in advanced countries and developed areas of the tropics for high milk quality are not practical for farmers in the early stages of dairy development, but they must be outlined as a goal for all farmers.

Milking stock should be disease free, and the milk from animals that are sick, that have mastitis or are within 5 days of calving, should be kept out of the public milk supply. Stock should have clean teats, udders, flanks, legs and tails before milking, especially for hand milking into an open utensil. Water buffaloes and sometimes cattle that have cooled off in wet muddy areas, should be washed off and dried before milking. Water used to wash the udder and teats should have a low bacterial content or be treated with chlorine before use (Andrews, 1978). Most farmers attempt to clean the udders before milking. For example, in India, very rudimentary cleaning materials like sand, silt and wood ashes are used by some. Surprisingly, milk bacterial counts are often low (below 100 000 per ml) using these methods (Gibson, 1966).

The milking area should be free of dust, mud, manure and flies, and be well ventilated. It is easy for most tropical farmers to provide a well-ventilated milking area, but not so easy to avoid the dust, mud and flies. Milkers should not have any infectious diseases, especially if they are hand milking. Their clothing, hands and forearms should be clean before milking, and preferably cleaned between milking individual animals. Wet hand milking (by wetting the hands with milk, spit or water) should be discouraged. A hygienic milking routine should include cleaning the udder, checking and discarding the first few squirts of milk, discarding abnormal milk and teat dipping after milking.

Milking utensils and equipment are the most important sources of bacteria in milk. Utensils should be seamless and preferably made from stainless steel. Bacteria will multiply quickly on poorly cleaned surfaces and in cracks and seams where cleaning is difficult and milk solids build up souring the next batch of milk. In many developing countries, any available container is used to collect and hold milk. Cooking pots, earthenware bowls, kerosene tins, goat and sheepskin bags, dried ruminant stomachs, wooden containers and gourdsare all used, frequently with an old block of wood or a bundle of straw on top to prevent the milk slopping out in transit. The methods have been used for generations, are difficult to change and the farmers are often unable to afford new and more suitable containers. Siegenthaler (1972) suggested that milk-collection centres lend small lidded cans to farmers for milk delivery, while Somjee & Somjee (1976) noted the presentation of new stainless steel pails, rather than a money bonus, for regular supplies of good-quality milk in India (Fig. 18.2).

After each milking, all utensils and equipment should be washed and cleaned to remove milk solids, sterilized to remove any microorganisms, then dried out to prevent any more organisms growing on the surface. Washing and rinsing well will suffice if the equipment can be completely dried out. A thin film of moisture on the surface allows bacteria to survive and multiply in warm climates. Likewise, milking machines must be well maintained, thoroughly cleaned and sanitized after each milking and rinsed just before the next milking (Fig. 18.3).

Proper sanitation is difficult and expensive for most tropical farmers. Detergents and sanitizers are not available or too expensive for many to buy. Water, often poor in quality and limited in supply, from wells, streams and small dams must

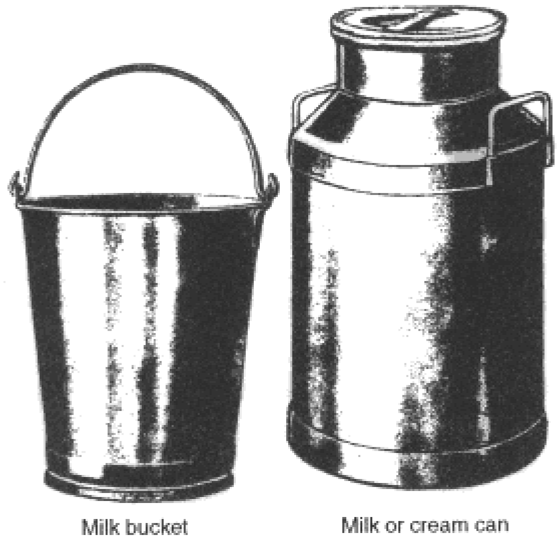

Fig. 18.2
Seamless stainless steel pails or cans are the most suitable containers for small volumes of farm milk.

Fig. 18.3
Milking machines need to be meticulously cleaned to prevent quality problems. All small parts, like the teat cap claw, must be regularly dismantled and hand cleaned.

be used for cleaning, with only the palm of the hand, a macerated stick or a bunch of straw to use as a brush. Mud, ashes or dried cow dung might be used as an abrasive (Warner, 1978). After washing or scouring with ashes, the utensils are usually rinsed and drained in the hot sun. Boiling water, steam or chemicals are rarely used to sanitize equipment in rural tropical villages. However, milk containers could be washed and sterilized at central collection points after being emptied. Figure 18.4 shows a simple steam chest for sterilizing equipment. Milk should be filtered immediately after milking to remove any dirt or manure, preferably using a metal mesh filter with a disposable cotton disc. A cloth may be used and reused after being sterilized by boiling for at least 5 minutes, followed by thorough drying in a clean place (Siegenthaler, 1972).

Holding Milk Quality

The best way to control bacteria in milk and to prevent it absorbing flavours is to cool it as quickly as possible after milking, and to hold it cool until processing or sale. Refrigerating milk at 10°C or less (preferably at 4.5°C) on the farm, in transport, and at collection centres and processing centres, is a desirable objective in terms of bacterial quality in warm climates. However, it is difficult or impossible in much of the developing tropics to provide refrigeration.

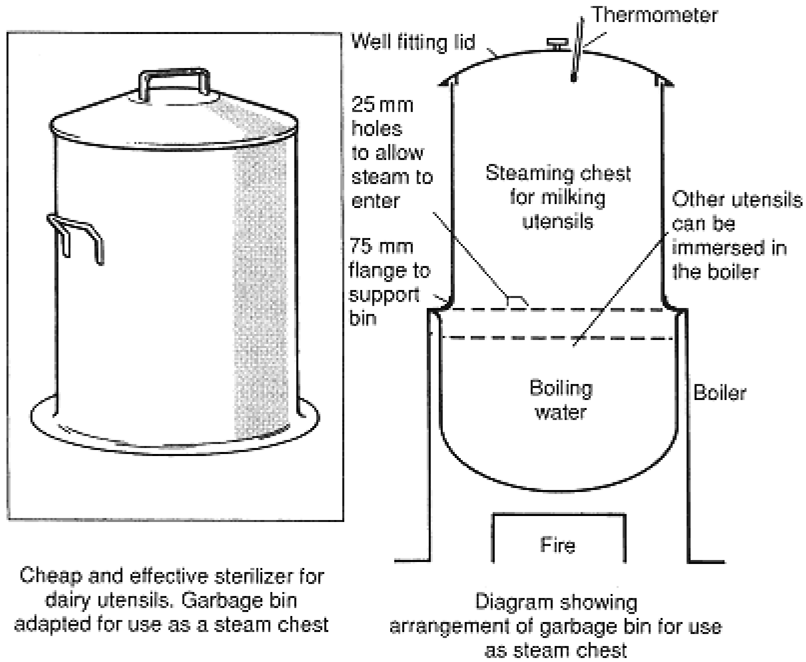

Fig. 18.4
A simple steam chest and boiler for cleaning and sterilizing dairy utensils.
(Source: Ashton & Laffan, 1951.)

Most developing areas have to import refrigeration equipment, many areas do not have the electricity supply to run them, and the cooling costs are much higher in hot conditions (Tentoni, 1965). Refrigeration is therefore too expensive and inappropriate in many cases, and is only used by large processing plants and developed dairy farms. It is virtually non-existent in the homes and villages of small rural producers, in small retail stores, or in the homes of poor city customers in developing countries.

If there is no refrigeration, milk should be cooled as much as possible by other means. The heat of fresh milk can immediately be reduced by immersing the milk containers in cold water or by running hot milk over a tubular cooler as pictured in Fig. 18.5. Milk should then be stored in the coolest place possible (Fig. 18.6), away from direct sunshine, and transported to the collection centre as quickly as possible: preferably in the coolest part of the day. In transit milk should be covered and perhaps kept cool with wet cloth covers over and around the container. Fresh and aged milk should not be mixed until

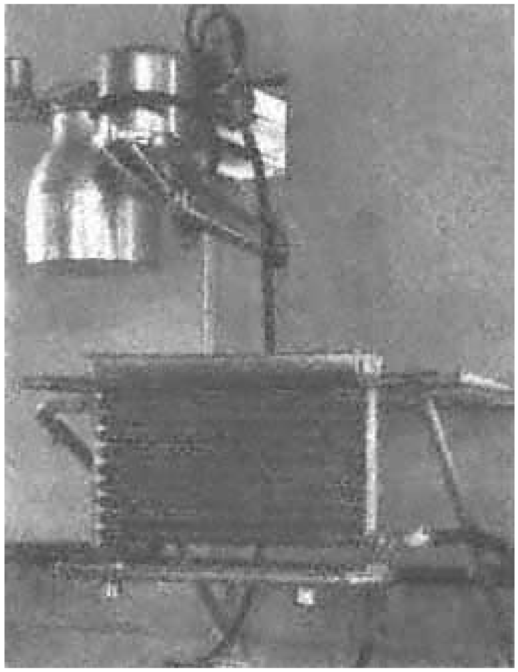

Fig. 18.5
A tubular milk cooler, with cool water circulating through it, can take the initial heat from fresh, hot milk.

Fig. 18.6
A covered stand with open sides and covered, well ventilated transport will keep milk cool in storage, on the farm and in transit to the processing plant.

they are at the same temperature and the milk should be stirred regularly to blend it and remove any taints.

Where there are no means of cooling, especially in very hot weather (above 40°C), milk quality seems to hold better if the milk is transported hot (Warner, 1978). Best results are obtained when the milk temperature is around 71°C or more, which is higher than that suited to the rapid growth of most microorganisms. However, there will still be problems with thermophilic bacteria which will develop if the milk gradually cools in transit to around 60°C.

There are many difficulties, besides lack of sanitation and refrigeration, to overcome before milk quality can be improved in developing hot countries. Slow and difficult transport, long distances, dust and mud all make it difficult for milk to reach market in good condition. As a result, alternative ways of preserving milk have been developed. In most regions of the tropics, milk is traditionally converted to more stable, longer-life products like ghee, fermented milks, curds or concentrated products, which hold their quality without refrigeration. These will be discussed in detail later. Milk may also be separated into cream and skim-milk on the farm, and the less bulky, less perishable cream sent to market daily or every second day. Most tropical consumers are also instinctively aware of the risks of drinking poor-quality raw milk, so have traditionally boiled all milk before using it. It is also common for milk to be moved within a couple of hours from milk-producing livestock managed in areas close to cities to consumers. Lack of refrigeration has forced vendors and farmers to deliver milk fresh to consumers' homes, to shops or distributing depots at least twice a day.

There may be a place for using preservatives in milk as a last resort, if milk cannot be rapidly cooled, transported or processed. Using preservatives is not a recommended practice, but may be the only possible way in the immediate future for milk to arrive at processing plants in reasonable condition in some warm developing regions. Pure-grade hydrogen peroxide (H_2O_2) is the only safe permitted preservative for milk which has been thoroughly investigated (Kon, 1972). A very small amount of H_2O_2 will kill most bacteria in milk but will not correct any deterioration, so should be added as soon as possible after milking. With H_2O_2, milk can be kept at ambient tropical temperatures for up to 24 hours (Siegenthaler, 1972). For H_2O_2 to work, the milk should be filtered so there is no organic matter, and not held in vessels containing copper or iron (like old tinned steel). For public safety, hydrogen peroxide should be added in a measured amount at collection centres. If this is impractical, farmers may be taught to add an accurate amount, for example in tablet form. All milk that has been treated with H_2O_2 must be treated for any residues at the factory or distribution centre. Residual H_2O_2 can then be destroyed with a trace of catalase (Siegenthaler, 1972). Preserved milk must still be heat treated by pasteurizing, boiling or sterilizing to remove any pathogenic bacteria. Modern developments may make it possible to use the natural antibacterial activity in milk combined with only a little chemical preservative (Korhonen, 1980).

Where large volumes of milk are collected to supply cities, the milk is usually heat treated before sale to make sure it is bacterially safe and to destroy the enzymes, especially lipase, which can spoil milk. Alternative methods of heat treatment are discussed later.

An alternative to holding milk quality is to convert milk into products at the farm or local collection centre, using technologies such as natural fermentation, souring of milk by natural juices, and separation of milk constituents by the combined action of acidity and heat (Phelan *et al*., 1995). Soured milk is a traditional food product in South Africa. Where temperatures are modest, semi-hard or soft cheeses can be made on the farm. This is common in South American and East African upland areas.

Legislation and Control over Milk Quality

In developing areas a different approach to milk quality must be taken than in developed countries where food is abundant and customers can afford and demand high-quality feedstuffs. Where food is scarce, the most important aim is to use all available food and to provide it as cheaply as possible. Ways for using even the poorest-quality milk must be studied (Siegenthaler, 1972). Therefore, at the start of any milk-collection scheme, milk must be enthusiastically accepted from all farmers, irrespective of quality. Lower-quality milk can still be used to make ghee, for example. If milk is always boiled before it is used, regardless of any previous treatment or quality check, and moved to customers within hours of production, extra-high quality standard are not so important.

Farmers must be capable, educationally and financially, of making the changes needed to satisfy quality standards. If the cost of improving quality outweighs the return to farmers, milk and milk products will become too expensive and both farmers and customers will return to unsupervised selling. Farmers must be provided with incentives for improving milk quality through better prices (premiums) and sure markets for good-quality milk (Van den Berg, 1990). As an example, in Costa Rica, the quality of milk received at factories did not improve until farmers were paid according to quality. After 14 years of the scheme the amount of substandard milk received had dropped from 40 to 0.5% of the supply (Montero, 1966).

Most products sold in developed countries must meet strict compositional standards. However, strict control over composition for village-made and home-made products is impossible in developing areas, and would be self-defeating, preventing the sale of important local foods.

There are many standards set for milk and dairy products in developed areas, and many tests available to check quality. Important physical quality tests include sensory grading, based on sight, smell and taste, to detect souring and off flavours, sediment testing for the level of foreign matter, temperature, specific gravity, weight, volume and sometimes freezing point, to indicate added water. The most important composition test has always been fat percentage which is usually the basis for payment. Total solids are also determined as is occasionally the protein content.

There are a large number of tests for determining the bacterial quality of milk ranging from total bacterial count (used for large volumes of refrigerated milk) to the methylene blue reduction test, which is a simple, valuable test for small volumes of unrefrigerated raw milk. Milk can be screened for mastitis by simple reagent tests or by counting leucocytes with sophisticated equipment. Antibiotics are simply detected in milk by an inhibitory substances test followed by a disc assay. Other pesticide and drug residues can only be detected with more sophisticated equipment.

Several tests are needed to give a good indication of milk quality. All tests have their limits so great care must be taken in conducting them and in interpreting results, especially for bonuses and penalties. Standards that are set in temperate or developed areas cannot be transposed unchanged to the developing tropics. For example, milk freezing point can be used to check whether water has been added to milk before sale. Work in Costa Rica (Montero, 1996) and northern Australia shows that cows in the tropics regularly produce milk with a higher freezing point than is considered normal in temperate areas, so caution is needed in setting a standard.

Developed tropical farms will be able to satisfy all reasonable quality standards, but it is important that small farmers are not discouraged by strict standards or penalties. Siegenthaler (1972) suggested that initial steps in improving milk quality should include issuing licences to all milk producers and sellers, and basing payment on volume and fat percentage, with a low price paid for what appears to be adulterated milk (from specific gravity (SG) (Fig. 18.7) and fat percentage tests). As time goes on, more accurate tests for quality can be added, starting with sediment and methylene blue reduction tests (Van den Berg, 1990). Allowance must be made in the standards for milk from all milking species.

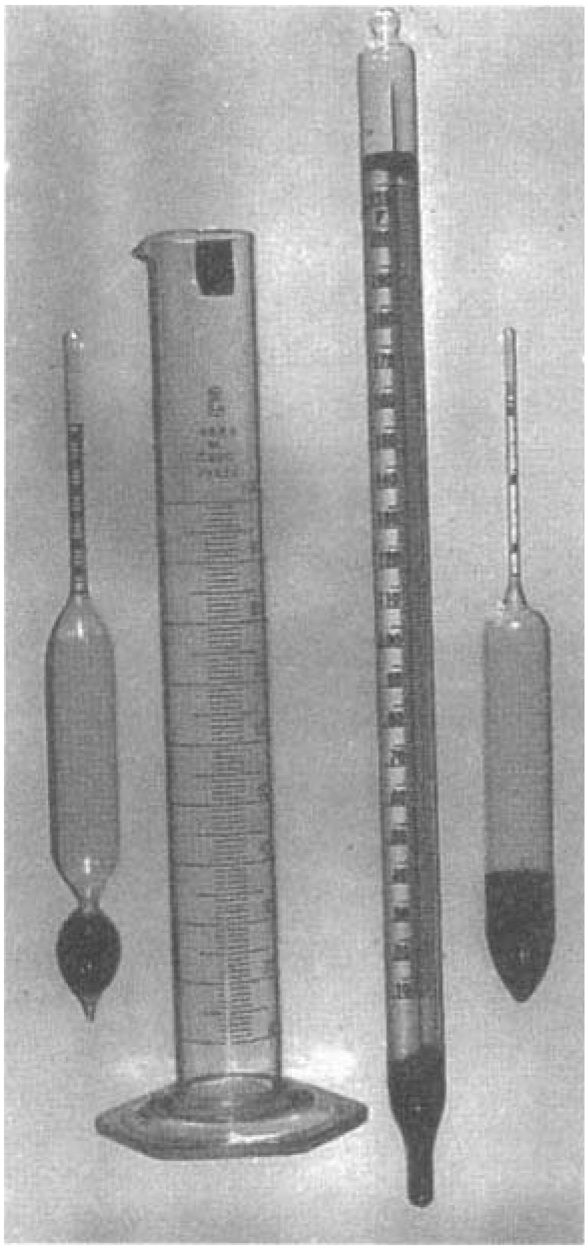

Fig. 18.7
Simple equipment for determining milk solids from specific gravity.

India, for example, legally recognizes milk from buffaloes, cows, goats and sheep as being suitable for sale.

Results of quality tests must be quickly reported to farmers so they can take action, and skilled advisers should be available to help farmers recognize their quality problems and solve them practically.

Organizing Milk Collection and Sales in the Tropics

It is not imagined that all tropical milk producers will become market-oriented. Village and rural people will continue to obtain milk and dairy products from their own livestock or local traditional sources. However, organized markets are needed for farmers with surplus milk and to provide milk for the growing cities. Most tropical countries now have some form of organized milk marketing including milk collection, processing, quality control and price regulation.

Organized marketing has generally been difficult and slow to develop, with many small scattered producers, a short season of milk surplus, long distances between farms and the city market, poor conditions for road transport, low hygiene during production and a lack of cooling facilities. In many countries, no matter who has organized milk supplies, dairy development has been accelerated by establishing village milk-collection and chilling centres within the reach of all suppliers. Producers deliver their milk soon after milking for bulking, immediate selling or chilling before being transported to larger city milk plants (Van den Berg, 1990).

Traditional Selling

Despite the move to organized marketing, only a small proportion of tropical milk is bought and sold through the official channels. In Kenya for example, with its efficient marketing system, 50% of milk available for marketing is sold through official markets (Brumby & Gryseels, 1985). The traditional private methods of selling are direct sale from the milk producer to the consumer, or through private milk vendors (merchants or middlemen). These methods can lend themselves to adulteration with water and contamination, but can be safe and legal if well supervised. Where farms and homes have no refrigeration, moving milk from the animal to the customer with little handling, and within minutes or hours, is a practical system and hard to criticize, especially where milk is traditionally boiled before use.

Some street herds of cows and buffaloes in India and Pakistan still provide milk directly to customers at their door or at the milk colony. Customers' utensils are filled directly from the udder and hygiene standards are not usually high. These herds are decreasing in number as cities modernize and health regulations become more strict. Also, many tropical milk producers convert their surplus milk into various longer-life products and sell them privately in local markets*dahi* and ghee in India, and sheep and goat milk cheeses in Western Asia, for example.

Private milkmen have played an important role in tropical milk selling in the past, providing a personal service and cheap milk to city customers. Milk vendors in India, owning one or two cans and a bike, pick up milk from farms within a few kilometres of the city and deliver it to the customer's door within hours. Private merchants also give Bedouin pastoralists the chance to sell their surplus milk by travelling around the nomad camps. Some make cheeses for sale in town markets by setting up simple cheese-making equipment near the flocks. Others collect and bulk milk for delivery to larger milk plants (Kolding & Koford, 1970). Hygiene and product quality are variable, but the system works and is difficult to compete with under such difficult conditions. The government of Lebanon has accepted this and has sponsored mobile cheese factories and mechanical milking equipment to help improve hygiene and product quality.

Moves to Organized Marketing

In developing countries the aim of organized marketing has been to gather the fragmented small milk producers in distant rural areas into an industry, in order to provide them with extra income, and at the same time to supply milk to as many city people as possible. Many tropical dairy industries have grown without any plan or organization. Others have been over-regulated by government, reducing farmer incentive and stifling management initiative. By far the most successful milk-collection schemes in the tropics, especially where there are many small suppliers, are the farmer-owned co-operatives. In fact the majority of milk sold in the world is handled by producer co-operatives. The alternatives are government or privately owned schemes which, on the whole, have not been satisfactory alternatives. Governments have a role to play in milk marketing by initiating dairy projects and milk-collection schemes, and regulating quality and price (Van den Berg, 1990). However, governments are not always the best at running the business side, as it is difficult for them to combine commercial efficiency with public responsibility.

There are several public sector milk plants in the tropics like the Worli Dairy in Bombay, India, and milk plants in Malawi. Private dairy companies have helped to expand the dairy industry in several tropical countries like Brazil, Jamaica, India, Jordan, the Philippines and Taiwan, but compared with co-operative schemes they have not led to the steady development of production by smallholders. Private processors may not always provide a reliable market for local farmers' milk and may be more inclined to use cheaper imported ingredients for recombining (Empson, 1985).

Farmer-Owned Co-Operatives

Farmer-owned co-operatives, with a commitment of service to suppliers, seem the most practical alternative to government and private organizations. Dairy co-operatives have been responsible for a great deal of development in milk collection, processing and selling in the tropical world. The well-developed milk industry in tropical Australia is based on co-operatives, originally many small district co-operatives that have combined in time into larger regional processing plants. In Kenya the largest dairy plant is co-operatively owned, collecting milk from around 50 000 smallholders in the semi-arid areas. Small mixed farms supply 75% of Kenya's milk (Brumby & Gryseels, 1985).

India has a large well-developed dairy industry with over 10 000 small village co-operatives, drawing together more than 2 million members to collect and process 2.5 million litres of milk (mostly from buffaloes) each day (Brumby & Gryseels, 1985). The concept of small producer co-operatives in India started in Annand, and its history of progress and good management led to the enthusiastic development of similar schemes. Every small village co-operative has 100200 members, each delivering around 3.5 litres of milk per day. Milk is brought to the collection centre twice a day soon after milking, and is usually tested for fat and quality, and payment is made for the previous day's delivery. The small village co-operatives are formed into district unions (containing over 400 village co-operatives each) to transport and process the milk. The Kaira Union of 783 village co-operatives, for example, has the largest milk products plant in the tropical world (Hunt McCauley, 1976). Kaira, plus five other unions in the same state, have joined into a federation to provide even more economic processing and better purchasing power for the members. The whole system is owned by peasant farmers and landless labourers, each owning one or two cows or buffaloes. All members have access to a range of services including AI, veterinary and extension services, stock feed and equipment.

Indian co-operatives do not try to prevent farmers from selling to other markets, but most farmers supply the co-operatives because of good milk prices, the range of services offered and the satisfaction of controlling their own activities. In order for large co-operatives to work efficiently, the Indian example suggests that there must be a reasonable number of farmers in the same area, bound by a network of transport facilities and that there should be a market to supply. Development will be slow, but must start with small, simple village collection centres, formed with the solid support of village members (Kurien, 1970).

A more recent example of the success of farmer co-operatives can be seen in Thailand. There were 114 dairy farmers in Thailand in 1962. In 1971 the first farmer co-operative, Nong Pho Dairy Co-operative, was formed and in 1994 membership had increased to 4400 farmers. A further 55 dairy co-operatives have formed since 1971, with a total membership of 20 000 farms in 1993, averaging 9 cows and 2000 litres of milk/cow/year (Charan, 1995). The Thai government has assisted in this development, largely through regulations requiring milk importers to purchase a similar amount of local product to that imported.

Farmer co-operatives also have an important place in dairying in Israel and Syria. In Israel, sheep's and cows' milk is produced by villages and large communal farms. Milking sheds and milk transport are frequently owned and managed co-operatively. There are many forms of co-operatives for milk suppliers in Syria. Each member may own his own animals, but milk his cows in a co-operative shed and receive a set amount of concentrate feed from the co-operative pool. Alternatively, animals may be owned co-operatively and all the dairy operations conducted collectively.

Milk Prices.

The prices set for milk and dairy products must represent acceptable costs to consumers and returns to producers. Most milk schemes in developing regions are also expected to have some welfare benefits such as improved nutrition among children and the city poor (Fenn, 1975). However, welfare activities should be supported by government or overseas aid, not by the developing dairy industry. If the majority of the population is rural, attractive producer prices benefit more people than very low consumer prices.

The benefits of milk schemes to city households are variable, but the nutritional needs of the urban poor are rarely met. For example, in India in 197374, 58% of city milk supplies were consumed by the richest 30% of households, while only 9% of supplies were used by the poorest 30%, despite the strong welfare aims of India milk schemes (Karunaratne & Wagstaff, 1985). Milk schemes must consider supplying wealthier city-dwellers with high-priced, good-quality milk and dairy products to make the developing dairy industry viable, but at the same time seek techniques for distributing safe, low-cost products for the urban poor. This has been attempted in Brazil with a three-tier milk price scheme, A-type milk being from sophisticated production centres and of higher price, and C-type milk being from smallholders and lower in price.

Prices to producers in some of the tropical developing countries compare favourably with domestic United States' and European prices being in excess of US$0.30 per litre (Charan, 1995). An emerging problem for many countries with developing dairy industries is competition from cheaper milk recombined in the country from imported skim-milk powder and butter-oil. In Jamaica, for example, the local producer price of US$0.27 per litre (1983) was dearer than the reconstituted product price of US$0.16 per litre (Empson, 1985). Preferences and local demands have also developed for recombined products, especially recombined sweetened condensed milk. It is not nutritionally advisable or commercially profitable to convert scarce local fresh milk to these preferred new products. Originally, imported ingredients were provided by developed countries to encourage local interest in dairy products and to even out seasonal milk supplies, keeping milk plants working at capacity. However, they are now a serious economic threat to some local developing supplies of fresh milk.

Governments and aid agencies in both the exporting and importing countries must recognize this risk to the local dairy industries, and provide them with protection against imports. India has import controls so that cheap imports cannot affect the price paid to their farmers (Empson, 1985), and Indonesia, Thailand and other Southeast Asian countries have controls on the ratio of imported to local milk products used in milk sales.

Milk Processing in the Tropics

Most tropical countries now have well-established, dairy plants producing very good quality products. The farmer-owned Kaira District Co-operative Milk Producers Union in India for example, produces a wide range of products including milk powders, baby foods, sweetened condensed milk, butter, ghee, cheese and casein, mainly from buffalo milk. Milk product manufacture on such a large scale is still not the norm in most tropical countries, as large dairy plants are generally not wanted in the initial stages of development. Experience has shown that it is best to start with a small-scale milk collection centre which sells the majority of its milk as cooled fresh milk. The next move can be towards heat treating the milk or making simple, locally accepted, less perishable products.

As already mentioned, most milk schemes find that they must supply two very different markets. Wealthier city-dwellers demand good-quality, heat-treated milk and luxury products like butter, fresh cream, ice-cream and cheese, for which the are willing to pay good prices. On the other hand poorer consumers require a continual cheap supply of milk which they can boil before drinking or making into traditional tropical milk products. These markets can be supplied either by very different milk-processing plants or by one plant producing the complete range. The various methods for treating liquid milk and producing tropical dairy products will be discussed later in the chapter.

It is very expensive to set up a sophisticated milk-processing plant in the tropics and most attempts to do so have faced similar problems. If possible, machinery and equipment should be manufactured locally in order to reduce cost, to ensure local back-up for servicing and spare parts and to provide local employment and participation in the project, However, in many countries there is not a well-organized manufacturing sector, so equipment needs to be imported, creating many difficulties in installation, maintenance and servicing. Dairy equipment must run for 365 days a year in good working condition. It must withstand sudden temperature and pressure changes and chemical corrosion from detergents and brine. It must be easily cleaned and sterilized after each run, and it must be flexible to cope with tropical milks of varying quality and composition, and changing supply and demand (Marque, 1973). Unlike processing plants in developed countries (Fig. 18.8), those in developing areas need to employ as many people as possible, especially unskilled workers.

Other basic necessities for setting up a successful large-scale milk processing plant in the tropics include a reliable local electricity supply, abundant good-quality water (or adequate treatment and recovery if necessary), a good transport network to get milk to the plant, a large reliable group of milk suppliers and a group of consumers willing to buy good-quality milk and milk products.

The alternative to sophisticated milk factories are small, simple village dairy plants, preferably located close to milk suppliers, to avoid spoilage and transport problems. Refrigeration, which is expensive, unreliable and mostly unavailable in the rural developing tropics, is not needed if farmers can move their cows' milk to village dairies within 2 hours of milking (34 hours for buffalo milk). Village dairies can be small, with a daily capacity of a few hundred to a thousand litres of milk, to avoid the need for cooling or storage (Bachmann, 1985). The dairies can act simply as a daily collection and selling centre for fresh milk, or can make simple, longer-life products like ghee, fermented milks and condensed milks, using traditional methods and village labour. The same plant can also be used to make other local products like jams, chutneys and fruit juices (Bachmann, 1985). All

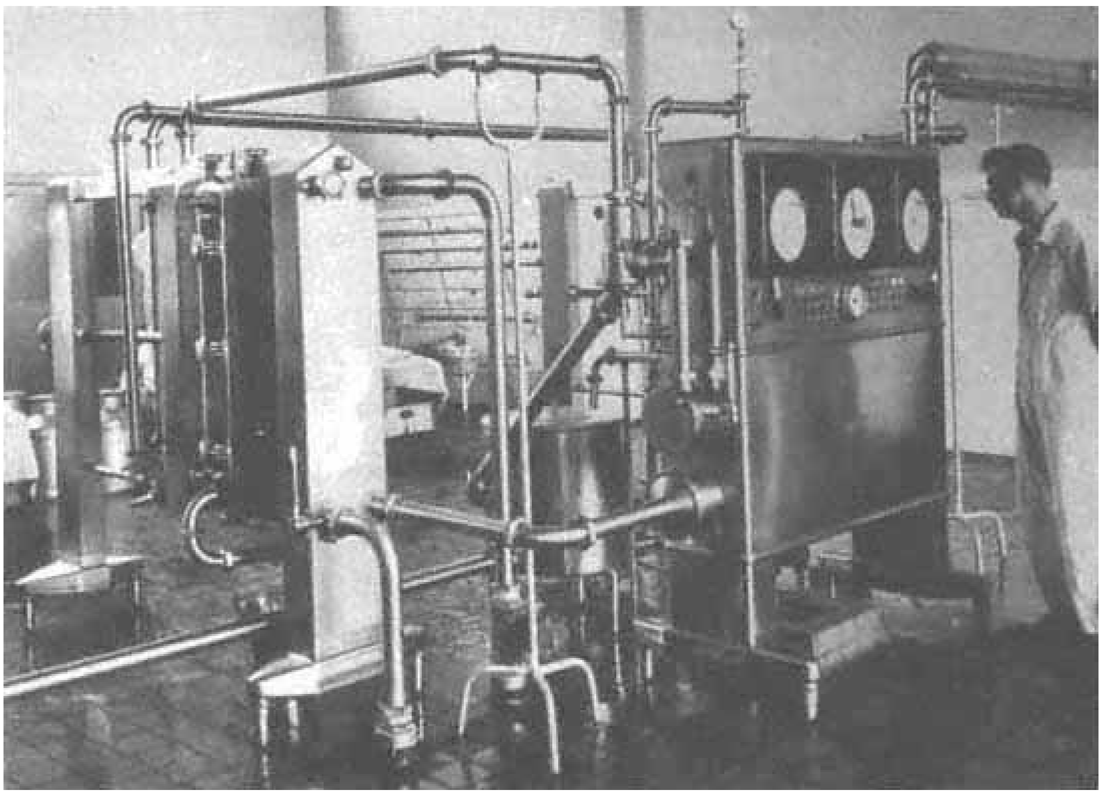

Fig. 18.8
Sophisticated milk pasteurizing equipment.

equipment and buildings can be made locally, and most village plants could be run with local energy sources including wood, biogas, water or solar power.

Milk for the Liquid Milk Market

Fresh raw milk is used in many parts of the tropics, from the consumers' own livestock or private sale and from village collection centres. Raw milk has a very limited shelf life without cooling, so must reach the customer within hours of being produced if there is no refrigeration.

People in warm climates know the dangers of drinking raw milk, so they boil it before using it for any purpose. In some countries all milk is boiled (whether or not previously pasteurized), making heat treatment before sale an unnecessary expense. The best method for boiling milk with the minimum of nutrient loss (through overheating, skin forming on the top and deposits on the pan) is to bring it quickly to the boil, stirring constantly, then immediately cooling it (Kon, 1972). A more sophisticated alternative is to place heatproof jars of milk in a deep vessel containing water above the fill line of the jars. The water is heated until the milk reaches 72°C and held there for 1530 minutes. The milk is then cooled quickly with ice or cold running water.

Heat Treating Milk before Sale

Pasteurizing is the most commonly used heat treatment for public milk sales. Milk is heated for long enough to kill any pathogens, although it will still contain some spoilage organisms. In well-developed areas where large quantities of milk are available, the continuous-flow process is used to handle up to 4000 litres/hour. Milk is heated to around 72.5°C, held for 15 seconds, then shock cooled to 4°C. In less-developed areas where smaller volumes of milk are produced and there is a need for simpler processing, batch pasteurizing is more suitable. The only equipment needed is a simple jacketed vat with an agitator and outside insulation. Milk is heated to 63°C by steam or hot water in the jacket, and held for 30 minutes. The jacket is then drained and filled first with cold tap-water and then ice-water (Siegenthaler, 1972).

Pasteurizing causes very little nutrient loss if well supervised. Because it still contains some microorganisms, pasteurized milk will sour within hours in the tropics if it is not cooled, so may still need to be boiled and used the same day where there is no refrigeration. At less than 10°C it will keep well for several days. Lack of refrigeration in many tropical countries means that pasteurized milk is unsuitable, except for immediate use. For liquid milk to be distributed and stored safely, it needs to be heat treated more severely to destroy all microorganisms and prevent any spoilage.

Milk is heat sterilized in some tropical countries. The sterilizing treatment involves heating sealed bottles or metal containers of homogenized milk to up to 120°C for 2030 minutes, usually using saturated steam under pressure (Kon, 1972). Sterilizing is expensive and requires careful technical control, so is difficult to use in most developing economies. Sterilized milk will keep for several months without refrigeration if unopened, but it is still not widely used in the tropics. The main disadvantage is its strong cooked flavour and creamy brown colour, which is not popular even in countries that traditionally boil their milk. Flavoured sterilized milk has a limited market in India. In the sterilizing process approximately 30% of the thiamine, 50% of the vitamin C, most of the B12 and some of the protein value of fresh milk is lost.

Ultra high temperature (UHT) treatment offers an alternative to sterilized milk; UHT milk has sterility but only a slight change in flavour and no change in colour. Under UHT treatment milk is heated to 130150°C for 18 seconds, usually by steam injection, then aseptically packaged in sterile cans, glass or plastic bottles, or plastic-coated aluminium-foil-lined containers. The process must be carried out in a continuous-flow heat exchanger and on a large scale, such as 2000 litres/hour several hours per day (Burton, 1973).

The shelf life of UHT milk depends on the heat used in the treatment, but it will usually last for 39 months without refrigeration until opened. If well processed, UHT milk is similar in flavour to pasteurized milk but has much better keeping quality. However, it is again an expensive process, only supplying markets that can afford and need long-life milk like ship and aircraft catering, and wealthier people without a fresh milk supply. UHT is identified as a major growth segment in dairy consumption in Southeast Asia (ASEAN Focus Group, 1995).

Other Processes

A few other processes are used to make liquid milk more acceptable and to improve its keeping qualities. Milk can be homogenized before heat treatment, to reduce fat globule size so they will remain dispersed and will not form a cream layer. The usual process is for milk at 60°C to be forced through a small orifice at high pressure (Kon, 1972).

Milk is sometimes frozen as a means of having a regular supply throughout the year. A rancid flavour often develops in cows' milk as the fat-globule membrane is broken by freezing, allowing lipolysis to occur on thawing. In northern Australia, good-quality goats' milk has been successfully frozen for several weeks without deterioration (Brown, 1980).

During pasteurizing and sterilizing, milk may also be vaporized to remove taints. Most taints derive from volatile materials that can be driven off by heating. The vacreator, for example, uses steam injection under vacuum to pasteurize and deodorize milk and cream (Warner, 1978).

Packaging and Distributing Liquid Milk

Methods of packaging and distribution should be tailored to the customer's requirements and income. In many cases milk is best sold unpackaged from bulk containers to provide the cheapest possible supply to low-income customers. Milk can be distributed safely from bulk tanks or cans into the customer's own containers, if hygiene is well supervised and facilities are provided for customers to give their containers a sanitizing rinse just before filling (Siegenthaler, 1972). In Indian cities, milk plants sell unpackaged milk direct to customers through automatic vending machines like the one shown in Fig. 18.9. Customers come to the vending stations which usually sell milk twice a day, around 06.00 and 13.00 hours. The customer places a container under the spout, inserts a coin or token and receives 500 ml of refrigerated pasteurized milk. Each booth handles approximately 300 litres/day. There were 150 such booths in Delhi in 1977, and by 1996 30% of milk sales were through these booths. The system is well suited to Indian cities where customers are used to bringing their own containers to milk vendors at a prescribed time (Jul 1977; Tuszynski 1978).

In most countries there are some customers willing to pay for packaged milk. Despite the higher cost, the advantages of packaged milk to the customer are convenience, milk that has better keeping qualities, is accurately measured and safe from adulteration. A variety of packaging methods are used, including returnable glass bottles, plastic bottles, cardboard cartons, plastic sachets and sealed cans. Packaged UHT and sterilized milk can be available continually in retail shops. Where shops and homes have no refrigeration, packaged pasteurized milk is generally sold for a limited time each day, or delivered directly to customers' homes by milk vendors.

Extending Limited Milk Supplies

Because fresh milk supplies fall short of demand in many tropical countries, ways have been found to provide milk to the maximum number of people.

Milking stock in most tropical countries produce milk with a high average fat content compared with temperate stock (over 6% compared with 34% respectively). This high-fat milk can be mixed commercially with an equal quantity of reconstituted skim-milk to produce milk with the same fat and solids content as most European supplies (3% fat, 8.5% SNF) The process, called

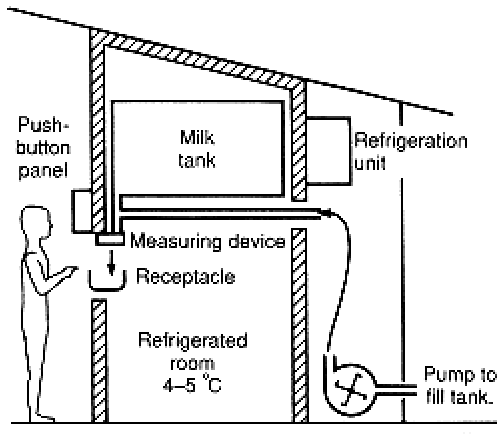

Fig. 18.9
Automatic bulk milk vending station
(diagrammatic side view).
(Source: Tuszynski, 1978.)

toning, was initiated in India and is now used widely in the tropics to make more milk available and at a lower price. It is a very good system as milk producers are well paid, while consumers are buying a cheap product (Kon, 1972). Most of the buffalo milk sold as liquid milk in India and Pakistan has been toned. Occasionally the fat percentage is reduced further to 1.5% (with SNF remaining at 8.7%) by double toning, to make limited supplies of milk even more available. Skim-milk powders are sometimes too expensive for developing countries to import at world prices for milk toning, so their supplies may be supported by foreign aid while local powders are slowly becoming available. The importance of toning to boosting milk supplies in the tropics can be seen in the increasing imports of skim-milk powder (or not-fat dried milk (NDM). For example, Brazil has increased the amounts of NDM imported from 35 000 to 60 000 t annually from 1990 to 1995, and Thailand from 38 000 to 62 000 t from 1987 to 1992.

An alternative is to incorporate some vegetable oils with milk solids and water to produce *filled* milk and dairy products. Most developing tropical countries produce some vegetable oils, like coconut, maize or palm oil, but have to import a large part of their milk products so they can make use of their own raw materials and reduce their imports by manufacturing filled milk. Most filled milk and milk products are made by dissolving skim-milk powder in water, mixing in vegetable oil then homogenizing and pasteurizing. Other ingredients are usually added to give flavour and body. The most common products are filled evaporated and filled condensed milk. Filled milk caters for 85% of the liquid milk market in the Philippines; Thailand and Cambodia also use vegetable oils in their recombined milks, and Malaysia is slowly increasing their use. Where milk supplies are plentiful and prices are low there is no need for this substitution, but for countries with limited supplies, filled milk can provide a lot of people with a cheap but good-quality food.

In many tropical countries where milk supply is deficient, recombining plants have been built to recombine imported skim-milk powder and butter-oil into liquid milk and milk products. Recombined milk is a common form of milk in Southeast Asia, particularly in Malaysia, the Philippines, Thailand and Indonesia. If well made, recombined milk is very similar to fresh milk. Most plants handle both fresh and recombined milk to make sure milk supplies are regular and sufficient. The problems that recombined milk has created, including competition with local fresh milk and changing consumer preference, to sweetened condensed milk for example, have already been mentioned.

Tropical Milk Products

Fresh liquid milk is traditionally used in developed countries, but is rarely used in the developing regions. A little may be consumed after boiling, and usually only in tea or coffee. A great proportion of the milk produced in tropical countries is converted into indigenous products like ghee or some kind of fermented or concentrated product that can be kept without artificial cooling. Most of these products are at present made in the homes but are gradually being made commercially. For most tropical milk-processing plants it is good business to produce these long-life locally accepted products rather than imitating dairy products from temperate climates like fresh butter, cream and cheeses which need expensive refrigeration.

Fermented or Soured Milks

Any milk held at warm tropical temperatures quickly turns sour as bacteria convert the lactose into lactic acid. Traditional milk drinking societies in the tropics have long recognized that this action helps to keep milk longer so most have developed a simple fermented milk product. Normal milk bacteria will sour milk but they can cause off-flavours and the milk may contain pathogens like the tuberculosis organism which will survive acid conditions. So, in most tropical homes, milk is usually boiled to destroy any organisms, allowed to cool, then inoculated with lactic acid bacteria (usually from a previous batch of soured milk) and kept warm until the desired souring and setting takes place.

It is difficult to classify fermented milks, but all the different names used refer to more or less the same product. In Spanish speaking countries the term is *leche agria*, on the Indian sub-continent it is *dahi*, in Western Asia and Arabian countries it is *leban* or *laban* and in southeastern Europe and Central Asia is it *yoghurt, kefir, matzoon* and *kumiss*. Many other local names are also used for fermented milk.

Leban is made in Western Asian countries from sheep and buffalo milks. It is usually eaten fresh in the home or sold daily in local markets. A similar product is made from camels' milk by some tribes (Kolding & Koford, 1970). In Kenya, *maziwa lala* is made in special gourds which have been washed, scrubbed, sterilized and treated with glowing embers. Cows are milked directly into the gourds and the milk is allowed to sour (without inoculation) for 2 days to produce a firm, smooth coagulated milk. The gourds apparently contain a specific organism which produces a consistent product (Shalo & Hansen, 1973). A similar product known as *mala* is made commercially by the dairy industry. Dahi is made in India from boiled buffalo, goats' or cows' milk by inoculation from the previous day's batch. It is held in earthenware pots for 1517 hours. Buffalo milk, with around 14% solids, makes the most popular dahi with a very firm, rich curd. Kefir and kumiss are alcoholic beverages made by adding kefir grains (wheat grain sized particles of clotted milk and microbes) to milk, fermenting for 8 hours then filtering off the grains to use in the next batch. Kumiss is made from mares' milk. The drink can be bottled, cooled and served like beer. Israel produces kefir commercially (Kon, 1972).

There is now a strong commercial demand for fermented milk products in many tropical countries. For example, one Kenyan milk plant makes huge amounts of *mala* each day from cultured buttermilk which keeps for several days without refrigeration and without developing further acidity. Most dairy texts detail methods for making fermented dairy products, but the equipment and bacterial cultures are often not available in the developing tropics. Siegenthaler (1972) suggested the following simple method. Milk is filtered, boiled, then cooled to ambient temperature by placing the container in 2540°C water. The milk is then inoculated at that temperature with the previous day's sour milk (using a ratio of 5% starter to milk) and kept warm until clotted and at the right acidity (310 hours). It must then be cooled to stop acid production and the whey separated off, or used quickly. For occasional cleansing of the culture he suggests the following method. Half a litre of sour milk should be heated, stirring continually, to 62°C, then cooled to room temperature. This will kill most pathogens and all coliforms but leaves some lactic acid bacteria. When the whey separates from the clotted part, some of the whey should be removed and mixed with an equal quantity of boiled milk. This should be covered and held for 2436 hours at around 30°C, then used as the new starter.

Cheese and Related Curd Products.

Cheese is solid curd with some or all of the whey drained off, either used in its fresh form or dried and further matured in storage. The curd can be formed by the action of lactic acid bacteria, organic acids such as lemon juice or vinegar, or rennet (containing the enzyme rennin from the stomach membranes of a calf); sometimes in the presence of heat. The same basic steps, followed for all cheeses, include curdling the milk, cutting the curd to drive out more whey, occasionally heating to shrink the curd and drive out more whey, salting, pressing or moulding; then for some cheeses, ripening or storing under brine, oil or fat. The preserving agents for cheese are acidity, salt or low moisture. Most cheeses will not keep long without cooling so they are not as common in tropical as in temperate diets. Cheddar-type cheeses in particular are not common as they exude fat when held in warm temperatures. Some form of traditional cheese, however, is produced in most tropical countries.

The milk of different species has different cheese making properties. Cows' milk can be made successfully into most forms of cheese. Buffalo milk is difficult to make into Cheddar cheeses, although commercially the problems are being gradually overcome (Ganguli, 1979). More usually, it is used to make soft, fresh cheeses like *jebin methfour* from Iraq and *cincho* from Venezuela. Camels' milk is difficult to make into any cheese and so is rarely used. Sheep's milk produces a very high yield of good-quality cheese, and cheese making is the most suitable way of using sheep milk. Goats' milk is used to make soft cheeses like *queso blanco* in Latin America, or semi-hard cheese like *halloum* in Western Asia.

Cheese composition, hence nutritional value, is very variable depending on the type of milk and treatment process used, but it is generally a high-quality protein concentrate, rich in calcium, riboflavin and vitamin A. It has great value as a supplement to cereal diets and its rich flavour improves otherwise bland staple diets (Kon, 1972).

Tropical cheeses can generally be divided into fermented and unfermented (white) varieties, but heat treating the milk is the essential start for making reasonable quality and safe cheese of any variety. The fermented tropical cheeses include *surati* and *srikhand* from the Indian sub-continent, and *labneh*, *ambrise* and *shanklish* from Western Asia. Srikhand is a fresh cheese made from cultured milk, pressed through cloth and sweetened with sugar. Surati also a soft high-moisture cheese, is made by heating milk to 77.5°C for 20 seconds, cooling it to 35°C, and adding 14 g of starter for every 45 kg of milk, plus sufficient rennet to give a firm curd in 1 hour. Thin, spoon-sized pieces are then placed in small baskets in layers, with salt added between the layers (2% of salt to weight of milk). The cheese is drained and turned several times, with the whey being collected. When the cheese is firm it is immersed in the whey to ripen at room temperature for 11.5 days (Warner, 1978).

Labneh is made from fermented sheep's milk (*leban*) by pressing it in sacks. It can be kept under oil for several months. Ambrise is made from sheep skim-milk in a similar way to labneh. Shanklish is made from ambrise by drying it to a heavy paste, forming it into balls and keeping it outside for 23 weeks. It develops a sharp taste from mould fermentation and will keep for more than 6 months in oil. Some of the Bedouin sheep's milk cheeses are flavoured with spices or crushed seeds and are generally stored in oil or wrapped in leaves for storage and consumption during the leaner dry season.

Unfermented white cheeses are very common in the tropics as they can be made under any conditions, requiring only heating and coagulation by acid or rennet. As stated previously, rennet can be obtained from the abomasum of young ruminants. In fact milk is sometimes still held in the stomachs of young ruminants to form a curd. Traditional unfermented tropical cheeses include *paneer* (synonym: *panir), jibbneh, queso blanco, sacapa* and *chenna*. Panir is a cream cheese made in India in a similar fashion to cottage cheese. Buffalo milk is brought to the boil, stirred, and as it rises to the boil, one tablespoon of lemon juice or vinegar is added per two and a half cups of milk to coagulate it. It is removed from the heat, allowed 5 minutes to curd then hung in muslin for 30 minutes. It is then pressed with a heavy weight if a firm cheese is required, cut into cubes and is usually cooked with vegetables. It can be stored for 6 days at 10°C. Chenna is also made in India in a very similar fashion from cows' milk. It is usually used fresh in sweets after kneading or pressing by hand. The famous

Bengali sweet, *rasgulla*, is made with chenna. In order to make the Bedouin jibbneh cheese, rennet tablets dissolved in salt water are added to lukewarm fresh milk. The curds are drained, cut into small pieces and pressed by hand in a cloth, then between two boards for 35 hours. The blocks are salted, turned and stacked. Some are eaten or sold fresh and the surplus are stored in brine or salted whey, and occasionally olive oil, in glass jars or tins. Latin American queso blanco is made in a similar manner to jibbneh. Sacapa, also a Latin American cheese, is made from the skim-milk left after separating cream for churning. Rennet is added to the skim-milk, the curd is broken by hand, drained, then placed in muslin bags. After draining the curd is worked by hand to a crumbly powder, mixed with salt and pressed in hoops. The whey is left to sit and the mouldy cream surface is churned and rubbed over the cheese. The salty, crumbly cheese is mature in 46 months (Siegenthaler, 1966).

Butterfat Products

The fat in milk has long been considered its most important component, being the only source of animal fat for many tropical people. It is easily separated from the water and solids and keeps reasonably well. Butterfat deteriorates like all other organic matter, but not as quickly as other milk components. Fresh or pasteurized cream is used in the developed areas of the tropics but is rarely used in developing areas. The exceptions are *kashta*, a heavy cream made by Bedouin people from boiled and settled sheep's milk, and *genir* (from Iraq) or *iüle kaymagl* from Turkey, a type of clotted cream made from buffalo milk and usually eaten for breakfast with honey or date juice.

In warmer areas the milk usually curdles before a cream layer forms, or the cream obtained is spontaneously soured. Butterfat is churned in several common ways including simply shaking receptacles, rocking skin bags back and forth, turning paddles inside larger vessels or by elaborate factory churns. With any of these methods the churn should be less than half full for butter to form quickly. Hand churning takes 3045 minutes in ideal conditions, longer in hot weather. Once the butter granules are 34 mm in diameter, the butter should be washed by adding an equal amount of water, churned again, well drained and then worked and kneaded to remove air and water (Siegenthaler, 1972). Butter made in the home from soured milk or cream is not normally used for fresh use but for cooking or making into ghee. Factory made 'cultured' butter is different as it can be pasteurized, neutralized and deodorized. Good-quality butter is made in many tropical factories, usually by batch churning of mechanically separated cream (Fig. 18.10). Salt is usually added to improve its flavour and keeping qualities and to mask taints. Unless it can be kept refrigerated, butter will deteriorate rapidly in hot weather. It will melt at 38°C, oozing out of its paper wrap or separating out into fat and water in its tins. Once this has happened it cannot be returned to its original condition. In some small tropical towns, packet butter may be kept cool by immersing it in water, but this reduces its bacterial quality (Warner, 1978).

The best means of preserving milk fat in tropical climates is to make it into ghee (synonym: *semni* in Arabic). Ghee has been used for centuries on the Indian sub-continent, and still over 40% of the milk produced there is used to make ghee. Any butterfat from low-quality milk, cream or butter can still be salvaged by converting it into ghee. Even low-quality ghee made in

Fig. 18.10
Simple butter packing equipment at a small dairy

plant.

villages can be collected, refined and clarified. Good-quality ghee will keep for several weeks without refrigeration, so it need only be sold in markets or villages once a week or so. Ghee is made in several ways, from either butter or cream, but the principal method is to evaporate most of the moisture and separate out the non-fat solids, leaving almost pure butterfat or butter-oil.

To make ghee, any form of butter or cream is heated to evaporate the water. Heating should continue until active boiling stops, indicating that most moisture has been evaporated off. Heating should then only continue with caution. Sufficient heating is indicated by the non-fat solids (protein and some lactose) turning amber. Overheating will cause an undesirable dark colour and burnt flavour to develop. The clear oil is then cooled, filtered and poured into containers. In homes and villages, most ghee is made from *desi* (village) butter, obtained from soured milk. In large dairy plants, ghee is made from unsalted fresh butter or fresh cream. In small-scale plants, good-quality ghee is most easily produced from washed cream. Milk is separated, then an equivalent amount of water is added to the cream before it is separated again. The cream is poured into an open, oversized pan and heated. It is stirred lightly at first, then more vigorously until a foam forms and rises rapidly to the top of the pan. The liquid is then allowed to settle, is filtered into containers and sealed when cold.

The milk from different species has different milk-fat characteristics, as mentioned earlier. Cows' and buffalo milk are regularly made into good quality butter and ghee. Sheep's milk ghee is highly prized by the Bedouin and can be kept successfully for over 1 year in sealed containers. Goat-milk butter generally has low keeping qualities, poor texture and easily turns rancid, so is not commonly made. Where goats' milk is important, ghee is made to improve its keeping. Camels' milk is difficult to make into butter or ghee. The butter is of very poor quality, so any that is made is used for cooking or converted into ghee. Camel-milk ghee has a much higher melting-point than cows' milk ghee (Wilson, 1984).

Concentrated Milk Products

Microorganisms cannot multiply without water, so concentrated and dried milk products allow milk nutrients to be kept much longer in the tropics without refrigeration. A type of condensed milk, *khoa*, has been made in India for centuries by boiling milk in an open shallow pan to decrease its volume by 7580%. The milk is stirred vigorously and scraped from the pan bottom with a flat paddle as it boils, until it forms a smooth, coagulated mass. Care must be taken not to allow milk particles to scorch and spoil the flavour. As it cools, the khoa hardens like firm, crystalline cheese, containing around 2530% protein. Quick cooling gives a preferred finer texture. Buffalo milk khoa is preferred for its richness. Khoa is usually sweetened and used as the basis for many Indian sweets and desserts. However, it is normally sold in markets in its unsweetened form, *mahua*, which remains edible for up to 1 week without refrigeration.

Canned condensed and evaporated milk has been available in the tropics for many years, mostly produced from recombined skim-milk powder, butter-oil or vegetable oil and sugar (for sweetened forms). Sweetened condensed milk is very popular in many countries as it has been their major form of milk supply for years. Sweetened, condensed skim-milk is unsuitable for children as it contains no vitamin A, but it can contribute vitamins, protein and minerals if it is used intelligently in a mixed diet (Kon 1972). Tropical milk plants produce condensed milk by recombining milk ingredients, adding sugar (if sweetened), holding the mix at 80°C for 15 minutes, then condensing it by boiling under vacuum until its volume is reduced two-and-a-half times. It is then cooled quickly to form small lactose crystals, and to prevent it thickening and browning. It is sealed in cans or tubes, then the unsweetened forms are sterilized. The 40% sugar content of the sweetened forms acts as a sufficient preservative. Condensed milk stores well at moderate room temperatures, with no change in its vitamin A and riboflavin contents, but it progressively loses its vitamin C and thiamine contents (Kon, 1972).

Evaporated milk is made by preheating milk to 95°C for 10 minutes (or at 120°C for 3 minutes), then concentrating it in vacuum pans to less than half its original volume at 5055°C. The evaporated milk is then homogenized and either UHT treated before aseptic filling into cans, or canned then heat sterilized at 115°C for over 15 minutes. The UHT treated milk has a more normal flavour and colour than the sterilized form which has a cooked flavour. Evaporated milk, stored at around 15°C, keeps well for 1 year without nutrient loss.

Cows' milk is still most commonly used for making evaporated or condensed milk, but buffalo milk is being successfully used in India (Ganguli, 1979).

Milk Powders

Dried milk powders seem a very suitable product for dairy plants in the developing tropics, so that milk can be kept without refrigeration, be transported easily, be mixed easily with other foodstuffs, and be available all year round. All tropical countries use skim-milk powder to some degree, especially those with recombining plants or those producing toned milk. It is certainly more desirable for the powder to be produced locally than having to import it. However, the cost of drying is high, and to do it efficiently a high volume of milk should be processed at onceat least 30 000 litres/day (Siegenthaler, 1972). As the dairy industries become larger, plants will be in a position to produce skim-milk powder, as many factories now do in India.

Whole milk, skim-milk and buttermilk can all be successfully dried. The usual procedure is to pasteurize the milk, condense it to one-third of its volume, then dry it by roller or spray drying. For roller drying, the milk is preheated and precondensed, then delivered in a thin film on to the smooth surface of steam-heated, rotating metal rollers (drums). The heat of the roller evaporates any water, leaving a sheet of milk solids, which are scraped off by a blade, then ground to a powder. Roller-dried powders are easily overheated, giving them a cooked flavour and making them hard to dissolve. However, modern, careful techniques can produce good-quality powders by this simple process.

In spray drying, the concentrated milk is atomized like a mist into hot air. The minute milk droplets dry instantly and drop to the bottom of the chamber. Heating is more uniform and less intense than roller drying, so spray-dried powders are more soluble, without a cooked taste.

Milk powders can be easily spoilt in the making or in storage, reducing their food value, so it is important that the best possible methods are used. Whole milk powder requires more care in storage to keep out air and moisture and an antioxidant to prevent a tallowy flavour developing. It is usually vacuum packed and stored at a moderate temperature. Skim-milk powder is cheaper to produce (other products are made from the fat) and easier and more stable to store in bulk if the moisture content is kept under 5%.

Other Products

Many other indigenous milk products are made in the tropics, but they are generally related to those already mentioned. The market for cold flavoured-milk drinks, frozen milk-based sweets and ice-cream is increasing in most tropical countries, but production is slow because of the lack of milk, facilities and expertise (Siegenthaler, 1972).

A few manufacturers in developing regions are equipped to make ice-cream with batch freezers (Warner, 1978). Ice-cream, strictly speaking, is made from a liquid component (full cream milk, skim-milk or water), a milk fat concentrate (cream, butter or butter-oil), non-fat milk solids (condensed or dried skim-milk), sweeteners, flavours and stabilizers (Kon, 1972). Hand-operated freezers (using ice and salt) are used in many tropical city streets to make small quantities of ice-cream, which is frequently sold frozen on sticks, in waxed paper or in plastic cups. *Kulafi* (synonym *koulfi*) is a popular ice-cream made in Indian and Pakistani homes and villages from milk, sugar, flour (wheat or pulse), flavours and sometimes colours. It is frozen in small 60 g covered containers in ice and salt brine, or dry ice. It has a hard, coarse texture from freezing without agitation, but is a very popular treat (Warner, 1978).

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19
Meat and Carcase By-Products

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Introduction

The possibilities for meat production from tropical environments are as diverse as the species that are utilized, the diseases to which they may be subjected and the cultures of the peoples who husband them.

As stated in the fourth edition of this book, there are many reasons why it is often more difficult to establish efficient meat production, processing and marketing industries in the tropics than elsewhere in the world. High ambient temperatures, particularly when accompanied by high humidities, make it difficult and/or expensive to store and transport meat. Inadequate services, such as water, electricity and transport may well add to the processing and marketing problems. In the more remote, extensive and arid environments a high proportion of the livestock may often be undernourished, of poor quality and be produced a very long way from markets. Also the occurrence of notifiable diseases, with consequent frequent imposition of quarantine regulations, periodically disrupt the free movement of livestock within a country and restrict export opportunities. In addition, the low average per capita income in some countries reduces meat consumption and the development of the industry may be limited by inadequate capital inputs, management skills and marketing expertise.

As tropical countries develop, with considerable human migration from rural to urban areas and an increase in average per capita income, there is likely to be an increase in meat consumption and changes in demand for specific types of meat. One major change in demand has been an increase in the consumption of poultry meat. This has led to the development of large-scale broiler industries in many tropical countries.

Some details of the production of poultry meat not discussed in previous editions are included in this chapter as are the possibilities for the production of meat from wild animals in extensive and arid environments.

Whatever the difficulties, it is wrong to assume that the basic knowledge and skills required to establish efficient and profitable meat production, processing and marketing industries in the tropics differ from those needed to sustain similar ventures elsewhere in the world. It is also true that the same basic knowledge is equally applicable to both village butcheries and meat factory enterprises.

For both sections of the industry, livestock production factors necessary to meet market requirements need to be understood and advances in meat-handling technology monitored so that relevant techniques may be introduced for the improvement of local practices. Operators must know and employ the best and most humane methods of converting live animals into saleable meat products. They must realize the relevance of ante-mortem management of the animal to post-mortem changes in meat quality, and it is of paramount importance that they understand the principles of hygienic production so that the meat that is sold and by-products that are disposed of, neither transmit disease nor cause offence to the community.

Animal Growth.

Factors of major importance for commercial meat production are the age and weight at which an animal produces a carcase of the desired conformation, the required degree of fatness and the efficiency of food utilization necessary to obtain these objectives. The ability of an animal to grow depends upon its breeding, sex and most important, the level of nutrition offered.

As animals grow the carcase becomes an increasing proportion of their liveweight. The ratio of muscle (lean) to bone increases and progressively more adipose tissue (fat) is laid down. This order of development results from the differential growth pattern of the individual components each of which, while continuing to grow, reach maximum growth rate at different stages of the animal's life. Thus increases in weight and stature are accompanied by continuing changes in body composition and appearance. The transformation of the long-legged, large-headed, bony-bodied, newborn calf to the rotund appearance of the well-fed bullock at maturity is physical evidence of these changes.

The normal growth curve for an animal from birth to physical maturity when liveweight is plotted against time is sigmoid or 'S' shaped. There is a period of slow growth immediately after birth followed by a more rapid increase until puberty, after which the growth rate slows down and finally ceases once physical maturity is reached. Similarly the animal's components have a specific pattern of development, each reaching peak production rate at different stages of the animal's life. The nervous system is well developed at birth to initiate the functions necessary to support life. Subsequently the bones pass through a period of maximum growth intensity to enable the animal to attain its adult stature. This growth phase is closely followed by increases in the weight of muscular tissue necessary to cover and activate the growing skeleton. After this peak of growth intensity has been reached fat deposition predominates.

This order of growth is presented diagrammatically in Fig. 19.1. In terms of relative maturity those animals having peak growths of body components close together, or early in life,

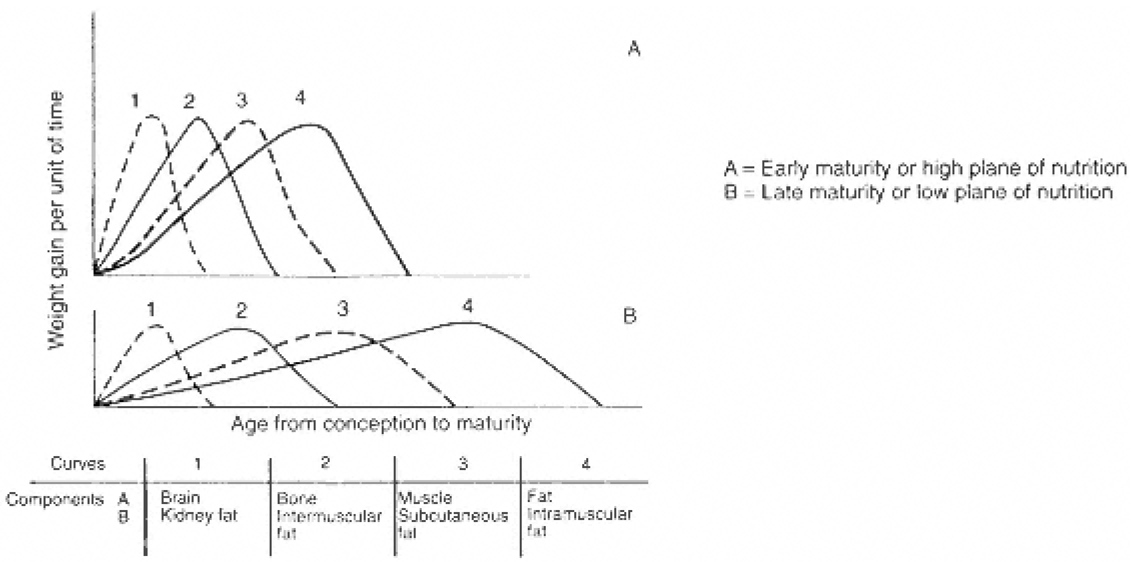

Fig. 19.1
Order of growth intensity development in an animal.
(Source: Pállson, 1955.)

represent either quick-maturing or well-fed stock while those with similar peak periods spread over a longer time-scale are slow maturing or inadequately fed. It is generally accepted that an early onset of fat deposition is associated with high nutritional levels and smaller breeds. Changes in the composition of grass-reared and concentrate-fed zebu cattle (Table 19.1) illustrate the effect of nutritional inputs on carcase composition and yield.

The Effect of Sex

Within a breed there are sex differences which affect carcase production. Bulls and boars convert food into carcase gain more efficiently than steers, heifers, gilts or barrows, and for similar levels of carcase maturity (fatness) they may be killed at heavier liveweights and produce heavier carcases. The effect of castration on the male is to change its growth pattern to one that is closer to that of the female, while the spaying of females encourages the onset of fat deposition. As entire males are more efficient converters of food into young lean carcases any escalation of the cost of stock feeds makes them the more suitable recipients for supplementary feeding projects; an advantage which is enhanced if the market demand is for lean meat. In these circumstances care will have to be taken that such animals are slaughtered before the male characteristics which nullify the growth advantages predominate. These include the increasingly coarse texture of the musculature, the progressive development of a heavy neck and shoulders and often objectionable odours and flavours; evident in old male goats and boar carcases, a characteristic which, in the context of pig production, is referred to as 'boar taint'.

Table 19.1 Comparison of carcase yields and composition of Boran steers; grass fed or stall-fed concentrates. (*Sources*: Ledger, 1965; Ledger, 1987 unpublished data.)

Item	Type of feeding				
	Grass		Concentrate	Grass	
Number of steers	10	10	5	10	10
Age (years)	1.5	2.1	2.5	3.5	4.5
Mean liveweight (kg)	258	351	352	442	562
Carcase yields					
Cold carcase weight (kg)	126	176	215	237	325
Carcase yield (%)	49	50	61	54	58
Carcase lean as % of liveweight	31.6	32.4	31.7	31.8	32.0
Carcase composition					
Total fat (kg)	17.8	25.3	69.0	53.2	93.4
Fat in side (%)	14.1	14.4	32.0	22.4	28.7
Total lean (kg)	81.4	113.8	111.8	140.8	179.9
Lean in side (%)	64.6	64.7	51.9	59.4	55.3
Total bone (kg)	25.4	33.9	28.4	37.7	43.7
Bone in side (%)	20.1	19.2	13.2	15.9	13.5
Hump weight (kg)	1.2	2.0	5.6	4.8	7.8
Hump in side (%)	1.0	1.1	2.6	2.0	2.4

(1) The slower growth of the grass-fed steers has resulted in their reaching heavier liveweights and carcase weights at lower levels of fat deposition.
(2) Although liveweight increases result from weight increases of all components the percentage of lean and bone in side decreases.

The Effect of Feed Deprivation and Compensatory Growth

During periods of nutritional adversity the initial loss of liveweight results from a lower weight of gut content. Subsequently, as nutritional stress increases, the demand on the body's components to sustain life will be the converse of that described for normal growth. In the first instance the needs will be met predominantly, but not entirely, by restricted growth of the animal's fat reserves. This may be accompanied by a slowing down of muscular development according to the age of the animal at that time. If food deprivation continues both fat and muscle will be catabolized to meet the animal's requirements for survival. If the deprivation is sufficiently severe or sustained the bone structure may suffer.

Once conditions improve, however, and food becomes more readily available, there is an abnormal growth rate of those components that suffered growth checks or weight loss. This frequently enables the deprived animal to catch up and achieve the same degree of maturity as its well-fed counterpart over a similar period of time (Table 19.2). The ability of an animal to recover depends upon the age of the animal at that time. Subsequently, recovery is controlled by the level of nutrition available and the time left to achieve the desired result. This recovery phenomenon is commonly referred to as 'compensatory gain'. As compensatory gain is associated with greater efficiency in the use of stock feed, considerable commercial use has been made of this phenomenon, particularly in the rearing of beef cattle. Stock reared in harsh environments and on poor pastures, that restrict the onset of fat production early in life, are better able to make good use of superior grazing or expensive concentrate feeds during the latter

Table 19.2 The effect of different levels of nutrition on the body and carcase composition of Boran steers. (*Source*: Ledger, 1987 unpublished data.)

Item	Treatment (nutrition level)							
	Control[a]		Starved[b]		Full-fed[c]		Recovery[d]	
Body composition	(kg)		(kg)		(kg)		(kg)	
External offal	28.7		27.4		41.0		41.6	
Hot carcase	100.9		83.3		153.3		153.5	
Internal organs	17.2		10.0		18.6		18.4	
Empty digestive tract	9.7		5.8		10.4		11.2	
Visceral fat	4.5		2.5		10.0		9.5	
Trimmings	1.7		1.2		2.7		2.7	
Tract contents (fill)	28.9		15.8		36.4		34.0	
Total components	191.6		146.0		272.4		269.8	
Carcase composition (cold left side)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
Muscular tissue (lean)	32.5	65.5	26.7	65.4	44.4	59.2	43.9	58.8
Adipose tissue (fat)	7.6	15.3	4.4	10.8	18.0	24.0	16.8	22.5
Hump	0.5	1.0	0.2	0.5	1.2	1.6	1.5	2.0
Bone	9.0	18.1	9.5	23.3	11.3	15.1	12.4	16.6
Total components	49.6		40.8		74.9		74.6	

a*Control group*: mean values for five steers slaughtered at 185 kg liveweight at the beginning of the trial.
b*Starved group*: mean values for five steers slaughtered after an induced loss of liveweight of 21% (from 185 to 146 kg).

[c]*Full-fed group*: mean values for five steers on *ad libitum* stall feeding from 185 to 275 kg liveweight.
[d]*Recovery (compensatory) group*: mean values for five steers recovering on *ad libitum* stall feeding and slaughtered at 275 kg liveweight.

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stages of fattening. High levels of nutrition early in life are conducive to an early deposition of fat so that, where lean carcases are at a premium, such animals have to be sold at a lighter weight. In such circumstances the producer is faced with a problem. Should he aim for the high-quality carcase which returns the highest price per unit of weight or should he produce a heavier carcase for a lower unit price in order to achieve a similar gross return? In the first alternative he runs the risk that if he fails to meet the quality grade standard he receives a lower unit price for a lighter-weight carcase. Whatever the circumstances the production of excessive fat is costly because it takes approximately four times the amount of food per unit of fat gain compared with a similar gain of muscle.

The relative responses of carcase tissues to differing levels of nutrition are illustrated in Fig. 19.2, to which the following explanation by Berg & Butterfield (1976) applies:

> 'The model [Fig. 19.2] allows for the partition of available nutrients on positive energy balance and also for the depletion of tissues in negative balance. The plane of nutrition is indicated as height in the intake tube depicted at the left. If the level is considered as producing pressure the influence on the various tissues, both positive and negative, can be visualized. Relative priorities of tissues for nutrients is depicted by their height. Thus if there are only small amounts of nutrients available the pressure is low and nutrients can be visualized as flowing into vital organs and meeting maintenance requirements. There would be insufficient nutrients to bring about any growth in bone, muscle or fat.
>
> On a plane of nutrition which provides for slow growth (depicted by a horizontal line on the model) muscle and bone receive nutrients required for their growth but there would be an overflow into the fat depots. It is probable that muscle growth would not be at a maximum rate, unless there is some fattening, as depicted by the 'medium plane' horizontal line. Under such circumstances muscle and bone growth would be near maximum but fat deposition would be restricted.

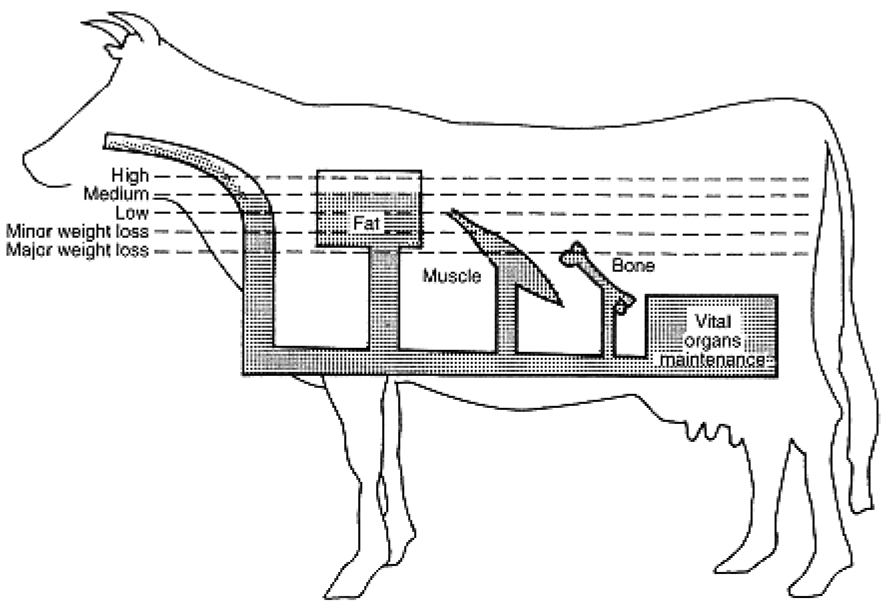

Fig. 19.2
A model of tissue priorities for nutrients and levels of nutrition sufficient to support differing levels of liveweight gain or loss.

> A high plane of feeding, such as *ad libitum* feeding of a high-quality ration, would result in surplus energy going to fat deposition since all other requirements are met.'

The model will also account for depletion of tissues from undernutrition. If fat depots are relatively full, they will be preferentially depleted, nutrients flowing from these depots to maintenance and vital organs. Depletion of muscles proceeds along with fat depletion in weight loss. The demand on muscle tissue becomes greater as fat stores are depleted until, when all fat stores are gone, survival depends on utilization of muscle tissue stores to maintain vital functions. Bone shows less depletion under weight loss conditions but some depletion is inevitable (i.e. assuming negative pressure there would be little repair of normal wear and tear). The depletion of bone would be greater under severe and prolonged weight loss. In the model depicted there would be weight loss from all tissues (because of negative pressure) and not selective depletion of fat until it is all used up, followed by depletion of muscle and then bone, as is sometimes suggested.

The Interrelationship of Growth and Economic Factors

The intelligent use of compensatory gain characteristics is of considerable importance in the economic development of the meat industry in much of the tropics as is the part that meat production has to play in land-utilization programmes. Unfortunately, in so many pastoral areas, especially in Africa, the periodic necessity to impose quarantine restrictions to contain disease all too frequently places a persistent curb on the development of a diversified grazing and fattening industry, as this depends upon the continual transfer of livestock from extensive grazing lands to intensive fattening units or improved pastures.

In practice animals reared for meat are seldom, if ever, grown to attain full physical maturity because the time involved and the expense incurred would be uneconomic. This is because:

• The longer the animal is kept the greater is the proportion of feed that is utilized for maintenance rather than for production and the slower the annual turnover rate per unit of land or housing space.

• During the latter stages of growth the main component to be laid down is fat, and in terms of food conversion this is the most expensive tissue to produce; also, if fat is present in excess of market requirements, it either reduces the value of the meat to which it is attached or, if removed, it has a low commercial unit value (this observation must be considered in the context of whether the market discriminates against fat meat or has a preference for it and is willing to pay for its production).

• For many markets the musculature from physically mature animals is too coarse and tough to command a price that secures a reasonable profit for the producer.

The optimum time for slaughter in mammals is generally accepted as being close to the onset of puberty, that is, before the growth curve begins to level off and fat depositions predominate.

A growth characteristic of considerable interest to the meat producer is the distribution of muscle within the carcase. Clearly it would be advantageous if animals could be selected which produced abnormally high proportions of muscular tissue in the most highly priced parts of the carcase, i.e. the hindquarter where the muscle to bone ratio is highest. Unfortunately there is little scientific evidence to support the hope that, within a species, such a selection can be made. Within species and for animals of the same sex there is a remarkably consistent and stable pattern of muscular distribution and development.

Early research into body composition changes suggested that the increase of carcase value with age was partly due to preferential deposition of muscular tissue in the hindquarter. More recent investigations indicate that the economic advantage of this situation is minimal, because such preferential deposition as does occur is not in the expensively priced muscles of the lumbar region and the upper portion of the hind legs (rump), but from increasing development of the cheap abdominal muscles of the flank, the latter being required to support the increasing weight of the digestive tract. Berg & Butterfield (1976) suggested that, irrespective of breed, 56% by weight of total muscle in cattle is located from where the more expensive cuts are made, i.e. the muscles surrounding the spinal column and in the upper portions of the legs.

In recent years there has been increasing interest in some abnormal 'freak' or 'mutant' cattle having exceptional muscular development, particularly of the hindquarter; this giving them the appearance of being 'double muscled' and they are alternatively referred to as 'Culards' or 'Doppelenders'. So far, there has been little progress in developing this trait for commercial purposes, difficulties experienced by the females during parturition being a major obstacle.

Comparison of muscular development between sexes suggests that with the approach of sexual maturity the superior development of the neck and shoulder muscles in males is an additional deposition of muscular tissue. This belies the belief, based on appearance, that mature males have less muscle in the hindquarters than do mature steers. The inference must be that, overall, mature males produce more muscular tissue per unit of carcase weight.

Comparison between species provides evidence that many wild game animals are superior to domesticated stock both in the greater amount of muscular tissue laid down per unit of liveweight and for the lower levels of fat deposition at maturity (see Table 19.9, p. 764).

While it is true that, during normal growth, bone and muscle follow a consistent pattern of associated development, fat deposition can be extremely variable, both in the gross amounts deposited relative to liveweight and in its proportional distribution. This variability is the major cause of conflicting interpretations of observed changes in the composition and appearance of both live animals and carcases. There are those who would go so far as to say that fat deposition is the only variable of major importance.

Some Characteristics of Body Components

Growth is necessarily associated with chemical change. Chemically the body comprises water, minerals, proteins and fat. Mineral deposition is mainly concerned with bone growth (ossification) and the degree of ossification that has taken place is a useful guide to the age of a carcase. The presence of cartilage instead of bone (*ossa cordis*) in the heart of calves indicates animals of less than 1 month old. The fusion of the *ischiopubic symphysis* (public arch) in cattle, to the extent that it can no longer be split with a knife, is indicative that the animal is over 2 years old. The progressive ossification of the tips of the spinal projections above the ribs is also indicative of age. In cattle these tips, which can easily be seen when the carcase is split down the length of the backbone into sides, show increasing ossification, and complete ossification can be expected after 6 years. The ossification process is more advanced in early maturing stock and those fed on a high plane of nutrition. The ageing of animals by reference to tooth eruption is dealt with elsewhere in this book.

Deposition of proteins is mainly represented by the increase in size of the muscles. On a fat-free basis the water content of muscular tissue is close to 77%, being slightly higher in young stock and showing a very small decrease with advancing age.

During growth chemical fat is deposited in the adipose tissues reducing their water content and increasing their cell size. Adipose tissue (dissectible fat) is the vesicular structure in which fat is deposited. The chemical fat content of these tissues may increase from 3% in a very young or emaciated animal to 90% or more in a very fat beast. The nature of the feed may influence the colour and texture of the fat as may also the age and breed of the animal. Too high a proportion of oil-seed cakes, rice bran or maize meal in the ration may be responsible for the deposition of soft fats while the feeding of cassava is known to produce hard fats. Dairy cattle, particularly those of the Jersey breed, are noted for the production of yellow fat. This is partly a reflection of age, partly of the inability of the breed to convert all ingested carotene into vitamin A. A high proportion of dairy cattle are slaughtered at the end of their working life when the accumulation of carotene deposits in their fat has effected a colour change. Consumers usually favour the appearance of a firm, creamy-white, fat.

The melting-point of fats has some bearing on the manner in which they are used. Internal fats, such as those surrounding the kidneys and the digestive tract (perinephric, omental and mesenteric depots) have higher melting-points, of the order of 49°C, than does the surface fat cover (subcutaneous fat) of the carcase that melts at approximately 32°C.

Ante-Mortem Management and Inspection

Ante-mortem management is concerned with the manner in which animals are handled from the time they are collected together for sale to the moment they reach the killing floor. The major defects which result from bad pre-slaughter management are bruising of the carcase, the extent and importance of which is indicated elsewhere and the depletion of body glycogen which results from fear, cold (particularly if shivering occurs) and/or physical exhaustion. The reduction of glycogen reduces the amount of lactic acid produced in the carcase after death which, in turn, affects its keeping and eating quality.

Bruising is a major cause of lost revenue because bruised tissue has to be cut from the carcase and this reduces the value both by virtue of the disfigurement of the product and the reduction in weight of saleable meat. In severe cases bruising may well result in the condemnation of a whole carcase. The ageing of a bruise is of some interest when attempts are made to ascertain the time at which the injury occurred and thus determine the responsibility for its infliction. The appearance at slaughter, if red and haemorrhagic, indicates recent bruising, less than 10 hours old, the colour becoming darker if the injury occurred up to 24 hours earlier. Bruises having a watery consistency may have been caused the day before arrival at the lairage (2448 hours), while bruises older than 3 days appear rusty brown or orange in colour due to the presence of the pigment bilirubin. Attempts have been made, with some degree of success, to date bruising more accurately by reference to the bilirubin content of the bruised area. An alternative method also considered is measurement of the electrical conductivity of the bruise, which is purported to increase up to 40 hours after the damage occurred.

Bruising is a particular problem in countries where extensively ranched livestock, unaccustomed to close herding, have to be collected and then driven or transported over long distances. The incidence of bruising can be materially reduced and the trauma of travel mitigated if the following considerations are recognized and acted upon:

(1) Cattle are dehorned as calves, or polled cattle are bred. Horns are recognized as the most common cause of bruising. The practice of removing only the tips of horns as a remedy has proved to be largely ineffective.

(2) Animals are herded together some days before they are due for transport. The mixing of animals unaccustomed to each other frequently results in skirmishing and fighting and the resulting damage can be costly. In this context it follows that the mixing of animals strange to each other, or of differing sizes, in saleyards, trucks or lairages should be avoided whenever possible.

(3) The transfer of livestock direct from the farm or ranch to the abattoir is preferable to their dispatch to a saleyard with all the extra cost of loading and unloading, the attendant risk of damage and the possibility of infection that such an exercise entails.

(4) In the long run livestock can be moved more quickly and with less damage if they are handled without anger or frustration. The use of wide straps to encourage stock movement by the noise they make on

impact is preferable to that induced by pain from the use of whips, sticks or thrown stones, all of which add to the possibilities of bruising or more serious injury. In circumstances of close contact when animals are passing through a crush, or being loaded on to a truck, the judicious use of an electric goad can be helpful.

(5) Animals should be sufficiently closely packed for transport to avoid their being thrown to the deck of the vehicle and trampled on. If there are insufficient animals to fill the vehicle then it should be sectioned off with strongly fitted partitions to provide the requisite area.

(6) The density of animals in a truck must vary according to the class of animal, the climatic conditions expected and the length of the journey. Hot, humid environments are the most exacting (particularly for pigs), but it must always be remembered that night-time in the arid tropics can be very cold. Uncomfortable conditions cause animals to become restive. Fear and shivering rapidly reduces the animals' glycogen reserves which, in turn, affect meat quality adversely.

(7) Evening, overnight and early morning travel is often preferable during the hottest time of the year. Care must be taken to ensure that midday rests are taken in shaded sites, a free flow of air is able to pass through the vehicle at all times and drinking water is freely available at 24-hour intervals. Periodic spraying with water from a hose-pipe or dousing with buckets of water can do much to alleviate heat stress.

(8) The driving of transport vehicles should neither be too fast nor erratic and sudden braking or fast cornering must be avoided. On railways the shunting of trucks should be minimal and carefully operated.

(9) The inside of trucks should be free from protruding nuts and bolts and sharp corners or edges. Floors and loading ramps must be well covered with litter to prevent animals slipping.

(10) The design of stockyards, both at the dispatching and arrival centres, should preclude sharp angles, projections and slippery floors. Crushes should be sufficiently narrow so that animals are unable to turn round in them. Some of the most severe bruising occurs when a leading animal half-turns in a crush, becomes jammed, and following animals pile up on top of each other as pressure builds up from the rear.

(11) Uncastrated males should be herded separately from castrates and female stock, particularly if any of the latter are in oestrus. Bulls should always be secured individually.

(12) The final possibility of bruising occurs at the time of stunning. If the stunning pen has been badly designed and the animal is allowed to fall too heavily or, upon exit, it drops from too great a height to the killing floor, post-mortem bruising may occur. Any delay in bleeding the animal after stunning, when the blood pressure is high, increases the possibility of rupture of the peripheral blood vessels and consequent disfigurement of the carcase. If a badly designed stunning pen is in use the problem can be alleviated by the use of a thick rubber mat on to which the animal can fall or be ejected.

It is unfortunate that the area of an animal most persistently subjected to bruising is the buttock or hindquarter, one of the most expensively priced parts of the carcase.

It is in the interest of all, that persons at the farm, the points of transit and at the abattoir should be able to recognize potentially sick, fatigued or otherwise distressed animals so that they can be removed, attention drawn to their condition and appropriate action taken to deal with them. At the farm or in transit this may mean slaughter or, if evidence of a notifiable disease is observed, a quarantine imposition. Similar observations at the abattoir would indicate those animals which need extra time to recover before being slaughtered and those which should be segregated and slaughtered at the end of the day's throughput so that their carcases and offal can easily be kept separate from that of healthy, undamaged livestock.

An all too common cause of carcase damage results from abscesses caused by unhygienic and careless use of hypodermic syringes. This mismanagement is compounded by the lack of care in choosing the site for an injection. This is all too frequently located in the hindquarter because that is the easiest part of the animal to reach when it is in a crush. Care should be taken to ensure that the injections are given where, should abscesses subsequently occur, they affect only the cheaper parts of the carcase, such as high up on the neck or low down on the rib cage or dewlap area.

The inclusion, by unscrupulous traders, of animals known to have been in contact with infectious diseases in slaughter groups, in the hopes that they will be killed before the disease becomes evident and quarantine restrictions imposed, is a hazard which threatens the industry at all times. In these circumstances lack of vigilance on the part of the inspectorate or the inadequacy of the training of its staff can be costly.

Symptoms of sickness or distress can be detected by careful observation of animals at the point of collection or in the lairage prior to slaughter. Suspect animals may be observed to:

- Stand away from the herd or flock and appear listless with their heads held forward and their backs arched.
- Possess eyes that appear dull and sunken, muzzles that are hot and dry and a tight skin with dull and rough hair.
- Salivate or have mucous discharge from their nostrils or eyes.
- Possess abnormally fast, intermittent or apparently painful respiratory movements.
- Excrete faeces that may be liquid, frothy or streaked with blood.
- Appear lame or stiff when moving.
- Show discomfort while urinating.
- Possess swollen lymph glands, particularly those in front of the shoulder (prescapular).

At the same time high infestations of external parasites or skin disorders should be noted.

All suspect animals should be removed to a quarantine area, some distance away, and preferably downwind from other livestock-holding areas. In quarantine body temperatures should be checked and closer examinations be made by qualified personnel.

Animals with excessively dirty hides or skins are a constant source of carcase contamination during evisceration and carcase dressing. For this reason it is important that collecting yards are kept clean and very dirty animals held back until the end of the day's run. There is some disagreement about the advisability of hosing down dirty animals prior to slaughter. It is argued that dirty, wet hides are more likely to contaminate carcases by virtue of the dirty water dripping from them than if they were left dry. There is some justification for this opinion, particularly if there is insufficient time for the animals to shed most of the water before slaughter. Presumably such an objection does not apply in abattoirs where reasonably clean animals are passed under a spray prior to entering the stunning chamber. The purpose of this routine is to cool and calm the animals as well as to damp down the dust.

The management of animals between the lairage and the abattoir can be greatly eased by the use of a 'judas animal'. This is an animal trained to lead stock to the killing floor but which is removed through a gate close to the stunning crate.

Unless animals have been reared in close proximity to the abattoir a resting period of at least 1 day is essential after arrival. Clean water should be freely available, but it is customary to withhold food for 24 hours prior to slaughter. This reduces the content of the digestive tract which eases future handling problems and thus reduces the possibility of ruminal content and faecal contamination of the carcase. Animals that have travelled long distances may require 72 hours or more to recover, so adequate resting, feeding and watering facilities must be available. The pens or lairages should be well fenced and have easily cleaned, impervious, well-drained floors with gullies leading to adequate effluent-disposal systems. The floors should have roughened surfaces to prevent the animals slipping. Shelter from the sun and prevailing winds should be provided and the pens preferably situated upwind and out of sight and sound of the slaughtering area. It is not always appreciated that some tropical environments impose wide ranges of diurnal temperature changes from daytime heat to nighttime cold. This is particularly so at high altitudes, and in arid regions during periods of cloudless skies. Animals moved long distances to changed environments are particularly vulnerable to these temperature fluctuations and protection from them in the form of windbreaks and shade is important.

It is recommended that 3.0 m2 lairage space be available for cattle, buffaloes and other large animals, 1.2 m2 for sows and boars and 0.6 m2 for sheep and goats. Isolation pens, paddocks or loose boxes should be available to accommodate badly injured, sick or suspect animals awaiting professional examination. If a decision is made to slaughter such animals this should be done at the end of the day's run so that the carcases and viscera may be kept separate from those of healthy stock.

Large-scale slaughter facilities for birds are different to those provided for mammalian livestock and are listed in the next section. Slaughter of poultry may be accomplished 'in-house' by large-scale production units or be organized so that small-scale producers can transport their birds to a central slaughter unit, pay for the slaughter facilities provided and either sell the carcases to the central unit or retain them for sale. The transport and management prior to slaughter of such birds is often poorly organized and sometimes inhumane.

Post-Mortem Changes

Immediately an animal is killed and its life-supporting mechanisms cease to function the process of tissue degeneration begins. In general the softer the tissue the more rapid its destruction. Eventually all that is left is the skeleton. The healthier the animal, the lower the ambient temperature, the drier the atmosphere, the minimal the microbial contamination both before and after death and the less the mutilation of the corpse, the slower and less noxious will be the rate of decomposition. Such elementary knowledge is the basis for sound slaughterhouse management.

Under natural conditions the rate of decomposition rapidly increases once the gases produced by intestinal bacteria burst the digestive tract and the highly active contents are spilled over the body. This is why it is advisable to tie off the two ends of the tract at the oesophagus and rectum to avoid contamination of the carcase by digesta or faecal spillage. Internally, within the carcase, the undrained arterial and venal pathways of the blood circulatory system, now inactive, provide easy access for contaminating agents to attack the tissues from within. It is to avoid this possibility that it has become a universal practice to drain the blood from animals either to cause their death, or immediately after they have been killed, stunned or otherwise anaesthetized. Apart from the possibility of aiding internal contamination the retention of blood in the meat, while enhancing its nutritive value, drastically lowers its sale value by providing a wet, exudative meat of unattractive appearance and poor keeping quality.

The progressive breakdown of animal tissues into simpler compounds, gases and water is a highly complex combination of chemical and biochemical interactions, many of which are not fully understood. A number of changes involve the presence of lipolytic, proteolytic and saccharolytic enzymes for the disintegration of fats, proteins and carbohydrates respectively, while others are initiated by bacterial activity. The nature and rate of many of these degenerative processes which succeed death are known to be controlled by the glycogen content of the animal at death and the rate and extent of the deep-body temperature drop in the carcase.

There are two aspects of post-mortem change of immediate concern to the meat producer. The production of a meat of good keeping quality which maintains an attractive appearance and the realization that a limited degree of degeneration is advantageous because it improves the texture of the meat, making it more tender and flavourful. Particularly is this true for cattle carcases. The rate and manner of protein degradation (proteolysis) is in part dictated by whether or not it results from bacterial or enzymatic action. Enzymatic proteolysis, which results in satisfactory 'ripening' of carcases, is favoured by an acid environment which, fortunately, discourages the growth of putrefactive bacteria.

Acid production in the carcase results from a complex series of chemical reactions that involve the conversion of glycogen present in the muscles into lactic acid. In the normal course of events under the aerobic conditions of the living animal, muscle glycogen is the fuel stored to promote immediate muscular activity as and when required, the main reservoir being the liver. A much simplified explanation of the way the animal's glycogen content can be reduced by pre-slaughter stress is by reference to the involuntary response to fear. Fear releases adrenaline into the bloodstream. This causes the glycogen to be converted into ATP (adenosine triphosphate), a neuocleotide responsible for the transfer of energy in living cells. The presence of the ATP induces interaction between the actin and myosin filaments within the muscles causing them to contract and initiate movement. Under the anaerobic conditions which follow death, the glycogen instead of being converted into ATP is changed into lactic acid. Under normal circumstances, when adequate glycogen is present and when during the first 24 hours the temperature drop of the carcase is to around 7°C, a change in pH from around 6.8 to something of the order of 5.5 can be anticipated. Such an increase in acidity promotes satisfactory 'ripening' and a bright red, attractive meat. Failure to develop sufficient acidity results in a dark, dry meat. If the increase of acidity after death is too fast, however, a premature onset of rigor is induced. This may occur if the fall in temperature of the carcase is too slow or, as sometimes happens, the temperature of the animal at the time of slaughter is abnormally high (a condition more commonly occurring in pigs than in cattle or sheep). Either of these circumstances results in a too rapid and severe onset of rigor mortis, causing an excessive contraction of the muscles and the production of a pale, soft and exudative (PSE) meat.

Immediately after dressing, a carcase is warm and soft to the touch. As it cools it becomes firmer and eventually, quite hard. This is partly due to the solidification or 'setting' of the fat and also to the onset of rigor mortis. The texture and colour of the fat may range from hard and white to soft or oily and yellow, depending upon the breed and age of the animal and the diet on which it has been fed. Rigor is a post-mortem phase of irreversible muscular contraction in which the overlaying filaments of the proteins actin and myosin cross-bond to form bridges of actomyosin. This causes rigidity and shortening of the muscles, producing denser and therefore tougher lean meat. To reduce the amount of cross-bonding it is important that the muscles should be extended as much as possible at the time of rigor. In practice this is achieved by leaving the meat on the carcase until the rigor phase is completed so that the muscles remain extended by virtue of their terminal attachments to the skeleton. Leaving the meat on the skeleton until required has an additional advantage in that the surface area open to contamination is kept to a minimum.

An attempt to improve meat quality by an alternative to the conventional method of hanging carcases from the hocks has been tried. The 'tenderstretch' method (Fig. 19.3) has found favour in some abattoirs. By suspending the carcase from the pelvis rather than from the hocks a greater strain is put on the back and hindquarter muscles, thereby limiting the contraction of these commercially valuable muscles during rigor. This method does have some disadvantages with regard to storage and subsequent cutting of the carcase. More hanging space is required and often the existing spacing between conventional hanging rails is insufficient to permit easy passage or reparation of the carcases. This is an important consideration because during cooling carcases must not touch each other. If they do, 'hot spots' will occur at the point of contact providing areas conducive to early putrefication. Distortion of the

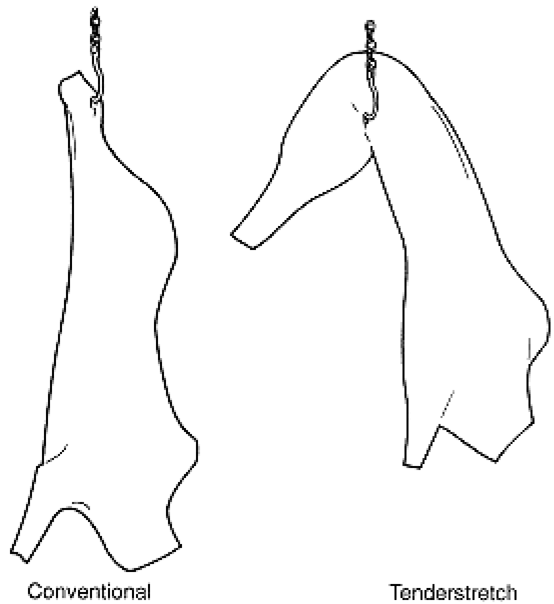

Fig. 19.3
Different methods of hanging carcases.

conventional shape of the carcase by the 'tenderstretch' method requires modification of the conventional methods for subdivision of the hindquarter into saleable joints.

Hanging and ripening procedures have come under scrutiny in recent years because of the high cost of the required refrigerated storage space. As a result, alternative methods such as hot boning, blast freezing and vacuum film wrapping are currently being used or considered. The use of electric shock treatments on hanging carcases to hasten the onset of rigor is another way by which attempts are being made to speed up operations.

Meat Preservation

The preservation of meat and meat products depends upon restricting or nullifying the activities of bacteria, moulds and yeasts. Such control may be achieved by temperature regulation, reduction of moisture content and the imposition of osmotic pressure changes by chemical means. Salting and curing combine the imposition of desiccation and osmotic changes. Sterilization frequently involves the use of moist heat applied under pressure as is used in the autoclaving of tinned products.

Refrigeration, the most commonly used method for preserving meat, is based on the evidence that most disease-transmitting organisms are inert at temperatures below 10°C and that microbial spoilage is almost entirely inhibited at temperatures below -8°C. However, even at lower temperatures, biochemical deterioration cannot be indefinitely controlled, the most common being the induced rancidity of fats that gives them an unpleasant flavour and appearance. The ultimate success of refrigeration depends upon the initial cleanliness of the carcase and the temperature control achieved during the cooling and storing process. The effect of these factors on the keeping quality of meat is shown in Table 19.3.

At one time it was thought that the cleanliness of the warm carcase could be improved by wiping it with a cloth immediately after dressing was completed. Such a practice proved to be counterproductive because of the impracticability of sterilizing the cloths. The result was that bacterial contamination was increased by the transference of bacteria from carcase to carcase. High-pressure water sprays (at an impact temperature of about 60°C) used for 20 seconds immediately after dressing are recommended for cleansing carcases prior to cooling and storage.

The design of refrigeration plants suited to differing situations is a highly technical exercise outside the scope of this book. Considerations involve:

- The rate and degree of temperature drop required.
- The air temperature, its flow rate and the relative humidity necessary to induce the requisite fall in temperature and to minimize the weight loss of carcases due to evaporation.
- The avoidance of excessive condensation.
- Adequate insulation.
- The provision of sufficient hanging space so that the cold air can circulate freely around the carcases.

Table 19.3 Relationship between the initial bacterial count and the number of days to the spoilage of meat. (*Source*: Gerrard & Mallion, 1977.)

Temperature (°C)	Initial bacterial numbers per cm2 and number of days to spoilage		
	0100 (superb hygiene)	1001 000 (very clean)	1 0001 000 000 (typical situation)
0	16	11	6
5	9	8	4
10	5	3	2
15	3	2	about 1
20	2	2	about 1

Note: Spoilage is considered to occur with the appearance on the surface of the meat held at 100% relative humidity of bacterial slime (associated with a bacterial count of 107 per cm2).

- Sufficient storage space to ensure that factory throughput is not interrupted.
- Cold rooms that are well lit and that can be cleaned easily.
- Provision for expansion of the abattoir throughput.

The categories of cold stored meat are generally recognized to be those of 'chilled' or 'frozen' but definitions vary from country to country. According to European Union regulations chilled meat is that which is cooled to 7°C and kept at this temperature, while offal must be cooled to 3°C. Such temperatures would appear to be too high for tropical conditions of storage and transport and the closer they could be kept to just above the freezing point of meat (-15°C) the better. The anticipated storage life for meat held between -1 and 0°C is shown in Table 19.4.

As can be seen in Table 19.5 the time taken to reduce the deep leg temperatures of chilled beef carcases may vary considerably according to local practices and specifications.

Frozen meat is that which is cooled to, and stored at, temperature well below its freezing-point. This method is commonly used for meat which has to be transported over long distances or stored for long periods. A commonly used criterion for this class of meat is that of a temperature reduction to, and for storage at, -10°C.

Table 19.4 Expected storage life of meat held at -1° to 0°C at a relative humidity of 90%. (*Source*: Gerrard & Mallion, 1977.)

Type of meat	Expected storage life (weeks)
Beef	<3 (45 with strict hygiene)
Veal	13
Pork	12
Bacon	4 (at -3 to -1°C)
Lamb	12
Edible offals	1

However, with the advent of modern methods of freezing, such as blast freezing, temperatures may be considerably lower, i.e. as low as -30°C. Estimates of the storage life of meats frozen to differing temperatures are provided in Table 19.6.

The advent of refrigeration, however, is not without its problem. If rigor is prevented by too rapid cooling thaw rigor may occur when carcases are subsequently thawed out and jointed. The thawed muscles, if detached from the skeleton, may contract to as much as 50% or less of their normal length. This is a phenomenon of particular relevance to lamb carcases, and is associated with considerable increase in the toughness of the meat. Another type of shortening occurs if rigor is retarded by too rapid cooling after slaughter. This is referred to as 'cold

Table 19.5 Cooling time of beef sides in commercial production. (*Source:* Gerrard & Mallion, 1977.)

Parameter	Location					
	United Kingdom			Europe (EU)		
Deep leg temperature (°C)	15	10	7	15	10	7
Weight of side (kg)	130	129	128	128	125	128
Average cooling time (hours)	25	34	40	19	27	33
Range in cooling time (hours)	1748	2362	2486	1227	2134	2845

Table 19.6 Recommendation for storage life of frozen meat. (*Source*: Gerrard & Mallion, 1977.)

Type of meat	Storage temperature (°C) and storage life (months)				
	- 12	- 15	- 18	- 25	- 30
Beef	58	69	12	18	24
Lamb	36	n.a.	9	12	24
Pork	2	n.a.	6	12	15
Offals	n.a.	n.a.	4	n.a.	n.a.
Bacon (unsmoked)	n.a.	n.a.	24	6	12

n.a. = not available.

shortening'. Excessive shortening of the muscles results if rigor occurs at temperatures below 10°C. It has been suggested that cold shortening can be prevented if any part of the carcase does not fall below 1012°C within 1012 hours of slaughter.

The chill room temperature for the storage of hanging carcases should be between 0 and 2°C. The maturing rate of a carcase is directly related to the temperature gradient: storage at chill temperatures could be expected to produce well-ripened beef carcases after a period of 23 weeks. An increase of storage temperature to around 14°C would achieve similar results in 23 days.

Another problem associated with freezing is the formation of ice crystals within the meat. If the fall in temperature is too slow large ice crystals form within the meat. These rupture the muscle fibres so that when the meat is thawed out for sale it exudes moisture (drip) resulting in loss of weight and flavour. The critical stage for large crystal formation is between -0.5 and -4.0°C. To avoid this problem rapid freezing through this temperature range is essential because at lower temperatures the size of the ice crystals is restricted. This can be achieved by blast-freezing techniques whereby supercooled air is forced over and around the meat.

The internal temperature of a carcase is that at the centre of the meat at its thickest part. In the literature concerned with cooling and cold storage the term 'half cooling time' is sometimes used. This is the period which elapses before the difference between the internal temperature of the carcase and the ambient air temperature has been reduced by one-half. A half cooling time of more than 24 hours is unlikely to prevent internal putrefaction. Often this first occurs around the bone in the thickest part of the carcase hindquarter and is referred to as 'bone taint'.

Inevitably there is a loss of carcase weight during cooling due to evaporation. The thicker the fat coverage and the more humid the environment the less the weight loss. Under normal conditions it is generally accepted that a cold steer carcase will weight some 2.5% less than its hot weight immediately after dressing.

Slaughtering and Carcase Dressing

Slaughtering and carcase dressing involves:

- Restraint of the animal for slaughter with the minimum of stress to man or beast.

- Rendering it insensible (unless religious or tribal custom decrees otherwise).

• Killing the animal.

• Draining away the blood.

• Preparation (dressing) of the carcase for sale in the manner appropriate to the animal species and the market demand.

• Meat inspection of the dressed carcase and those components removed from it.

• Assessment (grading) of the carcase with regard to its market value.

The facilities available for slaughtering and carcase dressing will vary according to the size and degree of sophistication of the abattoir. Whatever the circumstances the slaughtering of large animals, particularly cattle, without the aid of restraining equipment and lifting gear is unnecessarily arduous and inefficienteven if only one animal is to be handled. In its simplest form an abattoir comprises an easily cleaned killing floor where the animal is secured, slaughtered and bled; together with an adjacent dressing area where the carcase is prepared for sale and facilities are provided for meat inspection.

Slaughter arrangements for poultry are somewhat different to those provided for mammalian livestock and are separately considered.

Slaughtering.

Mammalian Livestock

The slaughter routine is sometimes dictated by religious beliefs and local custom but, whatever the method, there is universal agreement that efficient bleeding of the body is essential and that this is best achieved by severing the jugular veins and carotid arteries of the neck. Efficient bleeding greatly reduces the possibility of subsequent meat spoilage by post-mortem invasion of the carcase by microorganisms via the vascular, arterial and capillary pathways of the blood circulatory system. Bleeding results in the meat having a lower water content, a better keeping quality and a more attractive appearance.

To ensure efficient bleeding after slaughter and facilitate carcase preparation a mechanical hoist of some kind should be available close to the killing point. It should be sufficiently high to suspend the largest carcase likely to be handled, head downwards, from its hocks. The hoist may be on a moveable gantry to permit the body to be moved across the floor to the dressing area or, alternatively, the body may be transferred to an overhead carrier rail for the same purpose. The provision of hoists and carrier rails not only reduces the amount of physical work involved but also the possibilities of contamination of the carcase by excessive handling of the meat.

The commonly used humanitarian practices of either killing, stunning or anaesthetizing an animal to render it insensible before it is bled, are not universally accepted. Members of the Jewish, Muslim and Sikh faiths insist that such practices are untenable and unnecessary. They claim that death resulting from the severance of the jugulars and carotids by a single ritualistic cut across the throat is no more traumatic to the animal than the alternative methods practised. Moreover, they claim that their method ensures a more complete extrusion of the blood because the brain is undamaged and the heart continues to beat. This ensures active pumping of the blood until insensibility and death from anaemia rapidly intervenes.

The most common method of making an animal insensible prior to slaughter is to stun it with a blow to the head from a captive bolt pistol. According to the size of the animal and the estimated thickness of its skull, differing sizes of gun with appropriately charged blank cartridges are used to impel a stunning bolt to hit the head at the point of contact. Mature bulls obviously require heavier equipment and a more powerful charge than steers, cows, sheep or pigs. The use of live ammunition in slaughterhouses is not recommended because of the danger of accidental discharge or ricochets.

For small animals such as pigs, sheep and goats, electrical stunning is becoming a more frequent practice as an alternative method to induce insensibility. This involves the application of an electric current to pass through the brain. This is achieved by the use of a pair of insulated handled tongs the legs of which constitute the electrodes. With the tongs connected to the electric supply, and the operator protected by adequate insulation and such instrumentation as will indicate malfunction, the tong legs are applied to each side of the animal's head. The current is switched on and contact maintained for a period of at least 10 seconds. This results in instant stunning or unconsciousness for a sufficient length of time to permit severance of the blood vessels. If left unattended after stunning the electrocuted animals will regain consciousness after a few minutes and, apparently, are unaffected by the experience. A minimum of 75 V a.c., 50 cycles should be available at a current of not less than 50 mA.

The use of carbon dioxide gas for anaesthetizing pigs in gas chambers has found acceptance in some countries.

The restraint of cattle or larger animals that cannot easily be held manually can be effected by the use of a 'killing ring' or a stunning crate. Where only a few animals are to be handled daily a metal ring fixed to the floor (or low down on the wall) close to the hoist, provides a simple and efficient method for securing individual animals. The animal is led to the killing point by a nonslip noose of rope or chain around its neck. The end of the rope or chain is passed through the killing ring and the animal's head drawn down until it is secured close to the ring with little opportunity for movement. In this position it can be stunned or slaughtered according to local custom, providing that the latter method is humanely acceptable.

Where large numbers of cattle are to be slaughtered daily it is customary to use a killing crate or 'knocking' box. These are oblong, lidless crates approximately the width of the race along which the animal has been driven from the lairage to the killing point. The sides of the crate must be high enough and the length sufficient, to contain and restrain the largest animals likely to be handled. At the lairage end the animal enters through a doorway which closes behind it. The far end of the crate may be boarded in or have a yoke through which the animal's head protrudes and is secured. On the opposite side of the crate to the killing floor the operator of the stunning (captive bolt) pistol stands on a platform giving him easy access to the animal's head. When stunned, the animal falls and is ejected on to the killing floor through a horizontal trapdoor which runs the full length of the crate. Clearly, the killing floor must be located well below the level of the crate floor on to which the body should slide or roll. Once on the killing floor the throat is cut, a hind leg shackled, and the animal joisted, head downwards, on to a moving carrier rail. This transports the body to the dressing area. Most commonly the movement is adjusted to permit the body to travel some 68 minutes over a drainage gully which collects the blood and conveys it to collecting bins. In large abattoirs this travelling time is used to convey the body to a second- or third-storey dressing floor so that the offal and carcase can be directed, by gravity, to those areas designed to handle them.

Whatever the pros and cons of the different methods used for slaughtering may be, it is to be hoped that the method of its implementation will be as painless as possible and that adequate training and supervision will be given to all operatives. Apart from ethical considerations there are sound commercial reasons why this should be so because meat from maltreated stock is always of lower sale value than that obtained from sympathetically handled animals. If the glycogen content of the animal is depleted because of fear and physical struggle immediately prior to death, then the build-up of lactic acid in the carcase after death is inhibited. This results in the carcase being more prone to bacterial invasion and a decrease in post-morten enhancement of flavour and tenderness.

The pre-slaughter rodeos that sometimes precede the securing of animals prior to slaughter may be an exhilarating pastime for the participants and an irresistible entertainment to onlookers, but they are a very poor way to produce meat.

Once dead the animal is divided into two groups of components: the dressed carcase and the offal. The cash value of the offal is often considered to be equal to that of the cost of slaughtering and carcase dressing. In some countries this has led to the practice of 'sinking the offal' whereby the slaughterman, or perhaps more correctly the slaughtering organization, keeps the offal for sale in lieu of payment for the slaughtering service. Dressed carcases will differ slightly according to local practices and the species of animal slaughtered.

Poultry

In medium- to large-scale operations in which more than 1000 birds are slaughtered per hour, the slaughter process is partially or fully automated. The procedure is as follows:

- The birds are hung upside down by their legs from an overhead conveyor belt.

- They are killed or electrically stunned, bled, scalded and defeathered by machine.

- They are then manually or automatically eviscerated, the neck and gizzard being removed manually and the offal placed to one side.

- The carcase is then sprayed with chlorinated water, chilled rapidly, weighed and graded.

In small operations plucking (defeathering) will normally be carried out by hand.

The Dressed Mammalian Carcase

The dressed cattle carcase is that which remains once the animal has been bled, its head removed at the atlas joint, the forefeet severed at the knee joint between the carpal and metacarpal bones, the hind feet severed at the hock joint between the tarsal and metatarsals, the body eviscerated, the hide removed and the tail cut off close to the junction of the sacral and caudal vertebrae. Evisceration is the removal of the contents (viscera) of the thoracic (chest) and abdominal cavities, to which must be added the throat (oesophagus), windpipe (trachea) and the external genital organs and mammary glands (udders).

Once bleeding has been completed from the suspended body carcase 'dressing' can be carried out either by lowering the body on to a cradle or by transferring it to a moving conveyor belt where the operations are carried out in sequence by a number of operators stationed along the production line. The latter method is limited to large meat factories. The principles involved are the same for both methods and only the former is described in detail.

The purpose of the U-shaped cradle is to support the body on the back, feet uppermost, clear of the floor. The head and feet are removed and incisions made to a depth of the hide along the centre line of the chest and stomach. From this centre line further incisions are made up the insides of the legs from the fore end of the breast bone (sternum) to the knee and from midway between the anus and the scrotum to the hock. These lines of cut ensure a well-shaped hide when it is removed. At this stage, however, only so much of the hide is laid back from the carcase as will enable evisceration to be easily accomplished. The continuing coverage of the carcase by the hide during the evisceration process provides protection against contamination from dust, insects and accidental spillage of the digestive tract contents, etc. After laying back the hide from the centre line of the neck, the gullet or throat (oesophagus) and windpipe (trachea) are loosened from their attachments and the oesophagus tied off to prevent spillage of digestive tract contents.

A careful incision is made into the abdominal cavity at the rear end of the sternum (xiphoid cartilage). Great care must be taken to ensure that the knife-point does not penetrate the stomachs or intestines. With the blade uppermost, and one hand placed under the back of the knife-blade to prevent such an accident, the abdominal fascia is slit open until the pubic arch is reached. This arch is sawn through and the rectum loosened from its attachments and tied off to prevent spillage. Next, the sternum is sawn through along its centre line and incisions made into the hocks between the Achilles tendons and the legs. Into these incisions spreaders or cross-trees are inserted between the hind legs to prise them apart and provide a suspension point for lifting the body clear of the floor. Before lifting, the sternum is sawn through along its centre line to open up the chest cavity. The body is then lifted clear of the ground and the viscera drop away by gravity as they are loosened by careful severance of

their attachments to the carcase along the line of the spinal column. At this stage the kidneys and their surrounding (perinephric) fat are left in the carcase.

Subsequently the diaphragm is cut free from the ribs according to local practice (sometimes the thick portion attached to the ribs, the 'pillar' or 'skirt', remains in the carcase) and the contents of the thoracic and abdominal cavities are removed. Once the carcase is free of the viscera the hide is carefully removed with a flaying knife and the skinned tail removed. Care must be taken not to make damaging score marks on the hide or to disfigure the surface of the carcase. In a modern factory the hide may well be stripped from the carcase by a mechanical hide puller. Sheep- and goatskins are best removed by punching the skin clear of the carcase or by inflating the space between the skin and the carcase. An alternative method is to pull the skin off the carcase in the manner of taking off a glove. These methods ensure that delicate, top-quality skins are not damaged by knife scores.

The head, viscera and dressed carcase are now subjected to meat inspection for signs of disease or abnormalities. It is most important that all components should be clearly identifiable with the live animal and its place of origin so that any defects may be traced to their source of origin and remedial action taken. Plastic identity tags attached to components are well suited to this purpose. Alternatively, the carcase and offal must be kept together until both have been inspected.

For ease of handling cattle carcases are usually split into sides by sawing or chipping down the centre line of the backbone before dispatch to the chill room. Subsequently it is a common practice, prior to their dispatch, to quarter the sides between the tenth and eleventh ribs. This makes them easier to handle and conveniently separates the low-priced forequarter with its high bone content from the more expensive hindquarter with its higher ratio of muscle to bone. In cattle, the hindquarter from such a division may be expected to account for some 52% of the carcase weight.

Some differences may occur in the dressing of cattle carcases. The thick part of the diaphragm close to the ribs (the pillar or skirt) may be left in or removed from the carcase. Similarly, the kidneys and their surrounding fat (perinephric fat or 'kidney knob') may either be left in or removed, as may also be the fat lining the pelvic girdle (channel fat). In Europe those sides from which these fats have been removed are described as 'ex KKCF'.

Sheep and goats are 'dressed' in much the same way as cattle except there is no need to drop them on to a cradle. The carcases are neither split into sides nor quartered. Pigs have the skin, head and feet left on the carcase, those of the larger animals being divided into sides in a similar manner to that used for cattle, the line of cut down the spine continuing through the centre line of the head. Prior to evisceration the bristles or hairs are removed from the skin by immersing the body in scalding water (6063°C) and then scraping them off. If the water is too hot the bristles may become set in the skin and difficult to remove. Pig carcases give higher yields than ruminants because, being single-stomached animals, they contain less 'fill'. Also the head and feet remain on the carcase. These affect both the killing-out percentage and the proportion of muscular tissue relative to liveweight (Table 19.7).

As an alternative to fresh meat production carcases may be used for canned, dried or cured and salted meats or as minced meat mixtures for sausages, pie fillings, hamburgers, etc. For the latter purposes it is common practice to blend meats of differing qualities in such proportions as to meet the market demands for price and quality. Drying is a common method of preserving meat in several tropical regions. The meat may be dried in the sun or by the use of hot air ovens. A high fat content in the meat reduces the drying rate and some of the highest quality dried meat is made from the lean carcases of wild game. Condemned carcases may be milled, sterilized and dried to produce animal feeds and fertilizer. During these latter processes the fat is removed to improve the keeping quality and avoid rancidity. In the United Kingdom con-

Table 19.7 Carcase composition of boars, castrated males (barrows) and gilts slaughtered at similar liveweights. (*Source*: Newall & Bowland, 1972.)

Parameter	Animal type		
	Boar	Barrow	Gilt
Liveweight (kg)	92.3	91.3	90.0
Hot carcase weight (kg)	72.3	72.8	71.1
Dressing (%)	78.3	79.7	79.0
Muscle of carcase (%)	55.9	49.7	54.3
Fat of carcase (%)	33.9	41.4	35.6
Bone of carcase (%)	10.2	8.9	10.1
Muscle of liveweight (%)	43.7	39.5	42.9

demned carcases are not allowed to enter the food chain and in the future this could be the rule elsewhere.

Offals

The offal removed from the dressed mammalian carcase comprises: (a) the blood; (b) the external componentshead, feet, hide and tail; (c) the internal organsthymus (sweetbread), lungs and trachea, heart, pancreas, liver, spleen (melt) and kidneys; (d) the digestive tractoesophagus, rumen, reticulum, omasum, abomasum (only in ruminants), small intestines, large intestines, rectum and tract contents (digesta or 'fill'); (e) the internal fat deposits surrounding the heart (pericardial), the stomach (omental), the intestines (mesenteric), the kidneys (perinephric) and fat lining the pelvic arch (channel fat); and (f) the genitaliapenis, scrotum, and, if uncastrated, the testicles of the male and the vagina, uterus and udder of the female. Some details of offals from Boran cattle are provided in Table 19.8.

Offal may also include those carcases that have been declared unfit for human consumption and the bones and trimmings of healthy carcases from which the meat has been stripped for sale.

Offal is a highly perishable commodity and its utilization depends upon its suitability for direct sale in the raw state or the need to process it to improve its keeping quality and acceptability. On account of the diversity of community tastes it is impossible to provide a specific classification of what is directly acceptable. Mammalian offal that was sold direct to the public included cheek meat, tongue, brains, tail, thymus (sweetbread), heart, liver, spleen (melt), pancreas (gut bread), and kidneys. These items were sometimes collectively referred to as 'red offals'. With the announcement in Britain of a possible link between the disease known as bovine spongiform encephalopathy (BSE) in cattle and a new form of Creutzfeldt Jacob disease (CJD) in humans, some offals produced from slaughtered cattle that were previously consumed, have been eliminated from the market. It is not yet known whether a worldwide ban on the use of such offals will be required or could be enforced.

Kidney fat (suet) is a popular ingredient for pudding and pastry making, while the sale of any form of fat presents no difficulty in those communities where meat is a luxury and cereals are the staple diet. Blood is a highly nutritive food favoured by some communities. Much of the digestive tract is sold when cleaned and processed for consumption as tripe, or is utilized as containers for sausagemeat.

Carcase Assessment

There are two aspects of carcase assessment, one concerned with the carcase weight as a proportion of the animal's liveweight, the other being an estimation of carcase quality. The first consideration is commonly referred to as either the carcase yield, dressing-out or killing-out percentage. This is calculated as follows:

$$\text{Dressing out \%} = \frac{\text{Dressed carcase weight}}{\text{Liveweight}} \times 100$$

Care must be taken when using the formula for comparative purposes because the criteria used are not necessarily the same in all calculations. The dressed carcase will weigh more when hot, immediately after slaughter, than when cold some 24 hours or more later. The liveweight of

Table 19.8 Body and carcase composition of grass- and concentrate-fed Boran steers (mean of five steers in each group). (*Source*: Ledger, 1987 unpublished data.)

Item	Type of feed							
	Grass		Grass		Grass		Concentrate	
	Weight (kg)	As % slaughter weight	Weight (kg)	As % slaughter weight	Weight (kg)	As % slaughter weight	Weight (kg)	As % slaughter weight
Slaughter weight	192.0		276.0		350.0		352.0	
Cold carcase weighta	99.6	51.9	147.6	53.5	198.6	56.7	216.4	61.2
External offal	28.6	14.9	41.1	14.9	48.2	13.8	48.7	13.8
Internal offal	31.0	16.1	40.0	14.5	50.7	14.5	44.5	12.6
Gut contents (fill)	28.9	15.1	40.0	14.5	46.6	13.3	37.7	10.7
Weight loss	3.9	2.0	7.3	2.6	5.9	1.7	5.7	1.6
External offal								
Head	9.7		12.8		14.3		13.5	
Hide	13.8		21.3		25.0		26.7	
Feet	4.5		6.1		7.1		6.7	
Tail	0.6		0.9		1.8		1.8	
Internal offal								
Blood	9.4		10.5		13.0		11.2	
Heart	0.8		1.1		1.2		1.0	
Lungs	2.0		2.3		2.8		2.2	
Liver	3.9		3.9		4.6		3.5	
Spleen	0.9		0.9		1.0		1.1	
Rumen and reticulum	3.7		4.9		5.6		4.4	
Omasum	1.1		1.6		1.7		1.1	
Abomasum	0.6		0.8		1.4		0.8	
Small intestines	2.7		3.0		3.5		2.3	
Large intestines	1.4		2.2		2.1		2.1	
Omental fat	2.5		4.4		7.1		7.8	
Mesenteric fat	2.0		4.4		7.0		7.0	
Carcase composition (cold left side)		as % total		as % total		as % total		as % total
Fat	7.6	15.3	12.0	16.2	26.2	26.4	34.5	32.0
Muscle (lean)	32.5	65.3	47.7	64.6	55.9	56.3	55.9	51.9
Kidney	0.2	0.4	0.3	0.4	0.3	0.3	0.3	0.3
Hump	0.5	0.9	1.0	1.4	1.8	1.8	2.8	2.6
Bone	9.0	18.1	12.8	17.3	15.1	15.2	14.2	13.2

a Cold carcase weight is twice weight of left side.

the animal will vary according to whether it was fed and watered shortly before weighing or whether food and/or water had been withheld for some time. Therefore it is necessary to stipulate whether hot carcase weight (HCW), or cold carcase weight (CCW), full liveweight (FLW) or starved liveweight (SLW) have been used in calculations. Only results calculated on the basis of similar indices are directly comparable.

Non-ruminants of similar physical condition to ruminants will have higher carcase yields because they possess lower weights of gut content or 'fill'. Consideration must also be given to whether the carcases have been dressed in a similar manner. For example, have the kidneys and channel fats been left in or removed from the carcase? In general the fatter the animal the higher its dressing-out percentage. Estimation of the dressing-out percentage is a major, and often instinctive, assessment by the butcher when calculating the price he is prepared to pay for an animal.

Estimates of carcase quality involve visual assessment of shape, fat coverage, age, texture and colour. The estimation of 'meatiness' or the ratio of edible to inedible components is largely an appraisal of the shape of a carcase which, in practice, is an estimate of roundness. Angular carcases showing concave or straight-line silhouettes of the hanging hindquarter, and having poorly covered limbs are those which may be expected to have a high ratio of bone to edible meat. The more convex the outline and the greater the roundness of the buttocks, limbs and loin the higher the meat to bone ratio. When making comparisons between carcases of different sizes the relationship between the length of a carcase and its roundness must be taken into account.

Roundness is not only the result of muscular development but is progressively due to the deposition of fat over, between and within the muscles as the animal matures. The degree of fat deposition is critical to the suitability of carcases for some markets. The amount of fat is primarily judged by the amount and distribution of the subcutaneous fat on the surface of the carcase and the extent of the deposition of internal fats on the inside of the rib cage, surrounding the kidneys and the inside of the pelvic girdle. Lean cattle (<15% fat) (Fig. 19.4), will have a thin

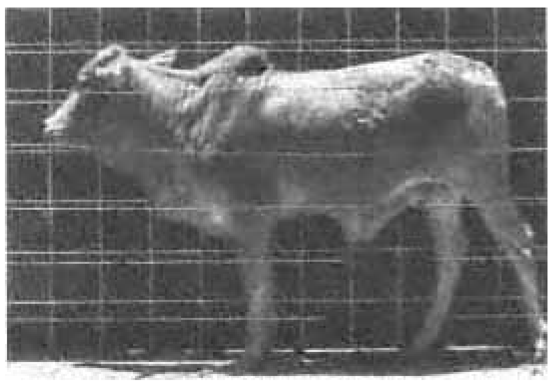

Fig. 19.4
A lean animal.

cover of subcutaneous fat which does not cover the whole of the surface, little fat surrounding the kidneys and little or no fat on the inside of the rib cage or lining the pelvis. Conversely, fat cattle (Fig. 19.5) (>30% fat), will have thick layers of subcutaneous fat, large deposits of fat around the kidneys and the fat lining of the inside of the rib cage will appear, in the hanging cold side (Fig. 19.6), as solidified rivulets draping the spaces between the ribs. The subcutaneous fat will also be judged on the basis of its colour (white to deep yellow), texture (firm and dry or soft and greasy) and its distribution (even or lumpy).

Cross-Section Assessment

A useful cross-section assessment of cattle carcases is that of examining the exposed surface of the rib when a side is quartered (often between the tenth and eleventh ribs). This exposes a transverse section of the longissimus dorsi or 'eye' muscle with its attendant subcutaneous, intermuscular and intramuscular (marbling) fat deposits (Fig. 19.7). There are numerous references in the literature to varying methods of predicting carcase composition from measurements of fat depth and 'eye' muscle area, some of which also incorporate carcase length and weight. In some countries the depth of fat over the 'eye' muscle at specified points is used for the classification of pig carcases.

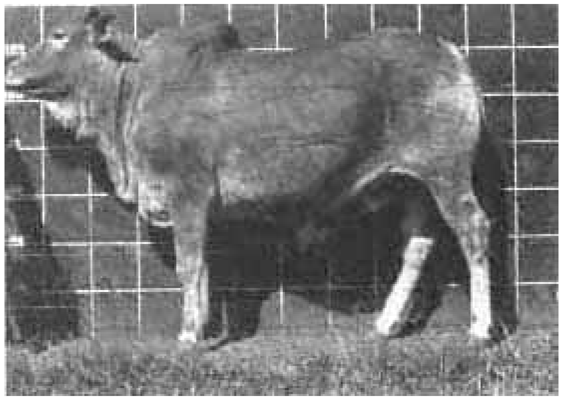

Fig. 19.5
A fat animal.

Fig. 19.6
Hanging carcase side of fat animal depicted in Fig. 19.5.

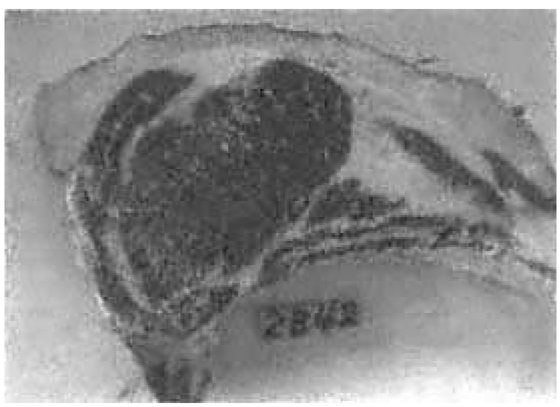

Fig. 19.7
Cross-section 10th11th rib of carcase side depicted in Fig. 19.6.

One of these methods is to record the mean of the depths of fat recorded at (a) the level of the last thoracic vertebra, and (b) at the first sacral vertebra, e.g. $(a + b)/2$. Alternatively, a mean reading of three measurements is recommended, those at right angles to the skin surface (rind) at points 4, 5 and 8 cm measured laterally from the centre line of the back at the last thoracic vertebra. To avoid the need to divide the carcase these measurements can be taken using a specially designed optical probe.

Biopsy and ultrasonic methods for the measurement of fat and muscle profiles in live animals are currently under continual experimentation. In practice there is considerable difficulty in introducing measurement techniques into factory grading schemes because of the time taken to implement them and the delay this causes to the rate of passage of carcases along the production line. Carcase weight and visual appraisal by trained graders is the most commonly used means of commercially evaluating carcases.

Meat Hygiene

There are no aspects of meat production that are not concerned with the problems of meat hygiene. They originate with the health and condition of the animal on the farm or ranch and continue with the manner by which it is transported and prepared for slaughter; the subsequent organization of its evisceration and carcase dressing; the preparation and storage of meat and by-products for sale; and the disposal of effluent and unsaleable waste products.

Involvement of Microorganisms

Meat hygiene is the practice of ensuring that there is minimal damage to meat and meat products by agents which will reduce the value of meat, render it unsaleable or cause illness or distress to the consumer. The difficulty of appreciating the problems relating to the maintenance of sufficiently high standards of meat-handling hygiene is because the major causative agents of disease transmission and meat spoilage, i.e. bacteria, yeasts and fungi, are mainly invisible to the human eye. Because of this, 'apparent cleanliness', though essential, is no guarantee of hygienic achievement. Therefore, some knowledge of bacterial activity is basic to an understanding of the principles involved in meat hygiene practice.

Bacteria are single-celled organisms which range in size from 0.8 to 10 µm and when suitably stained can be examined under a microscope. They multiply asexually by binary fission. Under ideal conditions it has been shown that a division may occur every 20 minutes, a production rate which can result in millions of bacteria being produced from a single cell within a 24-hour period.

Bacteria are all-pervasive, being found everywhere in naturein the air, in water and on virtually all exposed surfaces. Some are mobile and capable of self-propulsion in liquids, but the majority are transported by air currents and on any moveable object on which they may happen to alight. Rain may wash them out of the air and off plants, etc., into the soil and distribute them in animal and human water supplies. Vermin and insects distribute them by physical contact and through their excreta. They are inhaled and exhaled with every breath taken and the content of the digestive tract is inundated with them. Cracks and crevices in buildings and utensils harbour them as do porous materials such as bricks, wood, unsealed concrete and unglazed pottery. Contaminated water supplies are a common, dangerous and all-pervading problem. Additional factors which add to the difficulties of ensuring adequate standards of hygiene by harbouring bacteria and other microorganisms are inaccessible corners of buildings and cupboards; equipment that is not easily cleaned and sterilized; walls and ceilings subject to condensation; insufficient light; lack of screening from dust, flies, etc.; inadequate means for the immediate storage and subsequent disposal of unwanted by-products such as the contents of the digestive tract or 'fill'; dirty clothing and unkempt personnel; the presence of cats, dogs and/or vermin on the premises; and the possible presence of sick or 'carrier' staff members.

The bacteria of particular concern to the meat producer are the pathogenic bacteria. These may be responsible for producing poisons, either as a by-product of their activities (exotoxins) or directly within the cell (endotoxins); rendering meat inedible. Fungi and yeasts also affect the keeping quality and marketability of meat.

A class of bacteria of particular concern to the meat industry because of their toxic properties leading to acute discomfort and possible death of consumers are the *Salmonellae* spp. Populations of these, many of which are pathogenic, originate in the animals' intestines and become distributed on pastures. They may also be in foods of animal origin that have become infected. Host animals from infected farms may be responsible for spreading infection to clean animals during transit or while held in a lairage awaiting slaughter. Infection could result from the ingestion of contaminated food and water. Once ingested, bacteria rapidly multiply in the digestive tract of their new host and become a serious source of carcase contamination during the subsequent slaughtering and carcase-dressing routine. Salmonellae may also gain access to meat from human carriers, infected by, but not suffering from the disease, who contaminate meat through unwashed hands following defecation.

Most bacteria present in the live animal have a relatively narrow range of temperature in which they can thrive, of the order of plus or minus 2°C of the normal body temperature of their host. There are, however, some able to form spores (*Bacilli* spp. and *Clostridia* spp.), which can withstand considerable stress conditions and become reactivated once their environment improves. Examples of spore-forming pathogens are those responsible for tetanus ('lockjaw') and anthrax, both of which can be fatal to humans. In their spore form these bacteria are capable of remaining dormant, but potentially active, in the soil for many years. Spore-forming bacteria are of particular concern to large meat-handling and processing establishments in case they should become established in inaccessible parts of complex machinery.

The majority of bacteria can be killed by temperatures over 50°C and they are susceptible to light, desiccation and osmosis. The latter deterrents operate when meat is salted, cured or smoked and when disinfectants and antiseptics are used. Rapid cooling of meat greatly reduces bacterial activity but is not necessarily lethal. There are bacteria which are dependent upon oxygen for survival (aerobes) while others (anaerobes) thrive in its absence. The latter include many putrefactive, gas-producing organisms.

There can be few more favourable sites for bacterial growth than the body of a recently killed animal. The temperature, nutrient and moisture content and the near-neutral pH status of 6.86.9 of the carcase combine to provide an ideal environment for bacterial reproduction; particularly so once the blood ceases to circulate and the natural defences against invading organisms cease to operate.

In the healthy animal bacterial invasion is contained within the respiratory channels and the digestive tract by the nature of the tissue linings, supported by a second line of defence, the lymphatic system. This system acts as a protective screen throughout the body by containing bacterial invasions in a series of lymphatic glands and ducts, where they are destroyed by a concentration of white blood cells (leucocytes). It is because of this defensive role that the presence of swollen or abnormal lymph nodes provides visible evidence of disease. For this reason recognition of lymphatic abnormalities is a very important aspect of meat inspection routine.

Involvement of Endoparasites.

The digestive tract is not impervious to the invasion of the body by endoparasites, such as worms or flukes, which may utilize the animal as host for one or more of the stages of their life cycle. The invasive activities of flukes (trematodes), roundworms (nematodes) and tapeworms (cestodes) and their ability to form infective cysts within the body of the live animal have been referred to in the section on Parasitology (Chapter 2) where the damage by the all too frequent presence of tapeworm cysts in the carcases and organs of cattle (*Cysticercus bovis*) and of pigs (*C. cellulosae*) is discussed. These organisms are the larval stage of the tapeworms (*Taenia saginata*) resident in the digestive tract of cattle and of *T. solium* found in pigs. If undercooked or raw beef or pork, containing these cysts, is eaten by humans they may serve as hosts to the adult tapeworm and their faeces become infective. It is a very important part of the meat inspection routine that the milky white, opalescent cysts in 'measly' meat as it is sometimes called, should be recognized, the sites of possible infection known and contaminated meat condemned for human consumption. The cysts of most danger to the public are those in the musculature of the carcase.

In infected animals cysts may be found in the masseter muscles at the base of the lower jaw and probably in the oesophagus, heart, tongue and diaphragm. In Africa it has been found, contrary to European experience, that a favoured site is the triceps brachii muscles of the fore-shoulder. For this reason meat inspection procedures in the tropics often include incisions into these muscles to expose the presence of cysts. Whenever possible meat examination practices should avoid cutting into carcases more than is absolutely necessary because, not only does this spoil their appearance, but each new incision increases the possibility of introducing bacterial contamination.

The containment and eventual elimination of alternative host parasitic infections of meat can only be achieved by a reduction of the opportunity for the parasites to continue their life cycle. The exclusion of dogs and other carnivores from the precincts of butcheries and the elimination of rodents, other vermin, flies and insects will do much to achieve improvements. A change of eating habits from the consumption of raw or uncooked to well-cooked meat will greatly reduce the incidence of infection. Visual evidence of cooking at temperatures necessary to kill cysts is the absence of pink or red meat at the centre of a joint.

The rules and regulations relating to meat inspection vary between countries according to the prevalence of disease, the markets served and the levels of infection deemed necessary to warrant total or only partial condemnation of a carcase. Sterilization facilities available, such as freezing, irradiation, heat treatment, cold storage, canning and subsequent autoclaving, etc., also affect policy decisions.

With special regard to cysticercosis Thornton (1981) describes in detail the regulations and attitudes of a number of different countries to this problem. There is general agreement that total condemnation is essential if parasites, alive or dead, are found throughout the muscular tissues of a carcase, and if the flesh is oedematous. Countries also lay down differing regulations for the sterilization of lightly infected meat. There seems to be general acceptance that storage for not less than 10 days at a temperature of10°C will suffice. Countries which depend heavily upon export markets have to be particularly vigilant.

In general, post-mortem inspection of the carcase and viscera involves a recognition of the appearance, feel and smell of healthy tissues and organs. Abnormal colour changes, differences of response to palpation and unfamiliar blemishes all indicate a need for further investigation. Palpation involves feeling for such abnormalities as undue firmness, softness or flabbiness, lack of resilience or a lumpy consistency. If suspicions are aroused by the initial sensory examination then inspection by incision is indicated. Great care must be taken that the incisions, such as those concerned with the excision of purulent abscesses, do not result in spreading the contaminant to unaffected meat.

The Potential of Wild Game for Meat Production

As the human population of the tropics increases attention has focused on the best possible utilization of the semi-arid and arid rangelands, that in the past were sparsely populated. In East, Central and South Africa in particular, these rangelands have supported a large and mixed population of wild animals. There is no doubt that this fauna could be a very valuable asset.

In Africa in the 1960s, some of the first efforts were made to organize the commercial harvesting of meat from game in the dry rangelands. These efforts have continued intermittently until the present time (see Chapter 16) but have not been entirely successful. The cost of marketing game meat in an hygienic manner is high and without external or tourist outlets the demand can be limited.

The maintenance of the fragile environment in arid rangelands is difficult. There are recurrent droughts, domestic animal husbandry is often exploitive and productivity is cyclic in nature. Tourism has been developed into a major industry in arid rangelands where game abound in areas of great natural beauty, but there are severe limitations to the carrying capacity of many of these rangelands and some culling of surplus game may be a necessity. Under these circumstances it would appear that the harvesting of surplus game animals for meat and different modes of tourism could be symbiotic, though in general it would be necessary to cull and slaughter game for meat purposes during periods of the year or times of the day when tourists are excluded.

As a result of this situation and on account of a general lack of knowledge of the composition of the meat of African game animals the Meat Research Unit of the East African Agriculture and Forestry Research Organization (EAAFRO) conducted in the 1960s a survey of the carcase composition of a number of the wild game species commonly found in East Africa. Some important results of the survey are shown in Table 19.9.

All the species examined by Ledger (1968) provided meat acceptable for human consumption. As will be seen from the data in Table 19.9, compared with the meat of cattle, game meat is generally very lean and as Ledger (1968) stated, the leanness is not closely associated with toughness. The other major factor that the data in Table 19.9 show is the very low fat content of game meat compared to that of cattle. Game meat with a high lean and a low fat content should certainly appeal to the preferences of consumers in Western societies.

By-Products

By-products are the saleable commodities into which otherwise unsaleable offal, trimmings and bones from stripped carcases, and carcases condemned for human consumption, can be made.

Table 19.9 The carcase composition of some mature East African game animals. (*Source*: Ledger, 1968.)

Species	Sex	Liveweight (kg)	Carcase as % liveweight	Carcase lean as % carcase weight	Carcase fat as % carcase weight
Buffalo (*Syncerus caffer*)	Male	753	50.5	74.4	5.6
Eland (*Taurotragus oryx*)	Male	508	59.1	79.0	4.2
Gerenuk (*Litocranius Walleri*)	Male	31	65.0	80.6	2.0
Grant's gazelle (*Gazella granti*)	Male	60	60.5	79.6	2.8
	Female	41	59.0	77.4	5.1
Hippopotamus (*Hippopotamus amphibius*)	Male	1490	43.0	75.0	7.0
	Female	1277	41.9	70.5	10.9
Impala (*Aepyceros melampus*)	Male	57	58.1	81.4	1.9
	Female	42	58.3	80.8	2.0
Kob (*Adenota kob*)	Male	97	57.7	82.8	2.6
	Female	62	58.3	80.8	4.0
Kongoni (Hartebeest) (*Alcelaphus baselaphus*)	Male	143	57.2	80.6	2.2
	Female	126	58.1	79.0	3.9
Lesser kudu (*Strepsiceros imberbis*)	Male	92	62.1	80.5	3.3
Oryx (*Oryx beisa*)	Male	176	57.0	80.4	2.9
	Female	162	58.9	77.3	7.1
Thomson's gazelle (*Gazella thomsonii*)	Male	228	58.0	81.0	2.0
	Female	177	53.9	77.9	3.6
Topi (*Damaliscus korrigum*)	Male	131	54.2	81.7	2.3
	Female	104	54.0	81.6	1.9
Warthog (*Phacochoerus aethiopicus*)	Male	88	54.7	82.9	1.8
	Female	60	55.7	83.9	1.8
Water buck (*Kobus ellipsiprymnus*)	Male	238	58.6	82.6	1.0
	Female	181	58.9	78.9	4.0
Wildebeest (*Connechaetus taurinus albojubatus*)	Male	223	52.9	78.5	4.7
	Female	176	52.3	76.0	6.8
Cattle (zebu) (*Bos indicus*)	Male	484	58.0	68.7	13.7
	Male steer	470	57.6	54.8	28.6
Very (fat) animal	Female	395	59.4	53.6	32.9

They include leather from hides and skins, feathers from poultry, animal feeds and fertilizers (hoof and horn meal, meat meal, meat and bone meal, bone meal, blood meal, canned pet foods, frozen pet foods, etc.) and industrial products such as gelatines, glues, sausage-skins, pudding and fat containers, rendered-down fats for the preparation of oils and tallows, etc. Specific glands can be dissected out and used for the preparation of pharmaceutical products, but this is not generally practised unless trained staff are employed and suitable storage facilities are available.

In the United States, in factories making full use of all animal components, it is estimated that the dressed carcase accounts for 80% of the dead animal's value, the hide for 12% and the remainder for 8%. In many developing countries where such factories are few and far between, there is undoubtedly considerable loss of revenue through the wastage and mismanagement of potential by-products. While the detail of factory processing of by-products is beyond the scope of this chapter, some of the possibilities for better utilization of offal in smaller enterprises are mentioned.

Hides and Skins

As already indicated, hides or skins are the most valuable of the by-products because, if handled correctly, not only do they command a good price but they can be produced under primitive conditions and safely stored to await collection for transport to a tannery or buying centre.

Contrary to common belief the tanning process does not hide blemishes in the raw material but exposes them. Insect bites, scratches, indiscriminate branding and skin diseases all reduce the value of the final product. Rough handling at slaughter, dragging the hide across the floor, failure to wash it clean of dirt and blood and careless flaying all reduce the value of the cured skin or hide. Great care must be taken to ensure that putrefaction does not begin prior to offering the product for sale. As soon as possible after their removal from the carcase, hides and skins should be cleaned and the adhering fat and muscular tissues carefully scraped off to avoid damage. This is known as 'fleshing' the hide. With the tail switch removed, some 2.5 cm below the root, and any irregular edges trimmed, the hide is ready for preservation treatment. This may involve air drying, or the use of salt as a preservative.

Suspension Drying (Air Drying)

This is a simple, inexpensive and commonly used method for preserving hides and skins in the tropics. It requires little management, uses simple and inexpensive equipment and the products keep almost indefinitely provided that, during storage, they are protected from the hide beetle (*Dermestes maculatus*). This pest can easily be controlled by dusting the hides and stores with insecticides such as Gammexane®, etc.

All that is required is a rectangular frame constructed of local wood, bamboo or piping of such dimensions as will permit the largest hide to be stretched within it. Such a frame designed for cattle hides can be subdivided to accommodate four sheep- or goatskins (Fig. 19.8). Suggested dimensions are 2.7 × 3.1 m for large or 2.7 × 2.4 m for smaller hides. Hides are laced into the frame and stretched in the manner shown in Fig. 19.8, using string or vine for lacing. On no account should wire be used. Once the hides have been stretched the frames are supported vertically so that there is a free passage of air around both surfaces of the hide. Too slow drying may lead to mould growth resulting in subsequent hair slip while over drying may cause cracking. Shade drying is preferable to direct exposure to sunlight and this can be managed by aligning the frames in an eastwest direction and by providing overhead shade.

The hides or skins should be removed from the frames while they are still soft enough to fold lengthwise down the centre line of the back. Stored hides should be piled on slats clear of the floor, kept dry and frequently turned. To protect them from mould and insect damage the following powder formula is recommended: benzene hexachloride (13% gamma-isomer) 6%; boracic acid 4%; Santobrite® (Monsanto) 2%; and kaolin or other filler 88%.

Hides from cattle with humps must have the pocket pushed out with a stick to ensure that the inside dries out properly.

Dry Salting

This is a treatment used in conjunction with air drying, the underside of the hides being rubbed with copious amounts of salt. This prevents them from damage if the drying process is slow

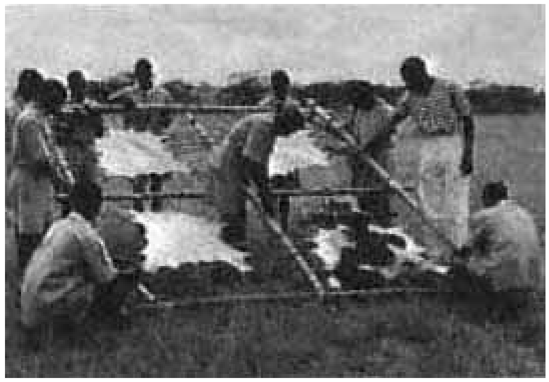

Fig. 19.8
Lacing skins in a frame.

because of adverse weather conditions or if there is to be a delay before they can be stretched onto frames.

Wet Salting

This is a treatment usually reserved for a situation where the daily throughput is large and a cellar with a temperature range not exceeding 16°C throughout the year can be built. Whenever the relative humidity exceeds 90% or the temperature exceeds 3042°C deterioration of the corium, the leather forming substance, begins. Wet salting consists of piling the hides on top of each other with copious amounts of salt laid between and around them. Curing takes approximately 3 weeks and the piles need to be turned and restacked every 10 days or so.

Meals and Fertilizers

Overgrazing practices, long distances from markets and the incidence of droughts and endemic diseases ensure that much of the slaughter stock in the tropics is substandard. Under these circumstances whole carcases contribute an abnormally high proportion of 'offal' production for which the most important outlet is the manufacture of meals and fertilizers. The names of these products are self-explanatory, i.e. hoof and horn meal, meat meal, bone meal, meat and bone meal, blood meal, etc.

The production of these commodities involves:

- Sterilization of the materials by heat treatment to eliminate the possibility of spreading disease with particular reference to BSE.

- Quick reduction of moisture before putrefaction sets in.

- The removal of fat from bones as well as meats to avoid subsequent rancidity.

Where the amounts of offal approximate 1 t/day or more it is economically and hygienically preferable to install a by-products plant. The offal may be derived from one or more slaughter-houses; particularly from those located at the end of long stock routes or in drought-stricken areas, where animals are too weak or emaciated to undertake the journey to an abattoir. The basic equipment, which may be static or mobile according to the circumstances, comprises:

(1) A boiler to provide the necessary steam.

(2) A drier, melter or cooker where the products are first sterilized under pressure (moist heat at a pressure of 1.5 kg/cm2 is recommended) and then dried.

(3) Equipment to remove excess fat by pressure, centrifuge or solvent extraction.

(4) A mill to reduce the dried, sterilized and defatted material to a powder.

(5) A packaging plant (for sacks, paper or polythene bags, cartons, etc.).

(6) A dry, well-ventilated and vermin-proof store.

(7) An efficient waste-disposal system so that local rivers, streams and wells do not become contaminated.

Hoof and Horn, Meat and Bone, Bone and Blood Meals

All of the above feeds and fertilizers can be manufactured in a suitably equipped by-products unit. Care must be taken that hooves are not included in meals intended for stock feeds as it will render them unpalatable. Alternatively the hooves and the stems of the horns, that are rich in collagen, can be collected and used for the manufacture of gelatine and glues. The horn stems and hooves can easily be separated from the horns and feet after immersion in hot water. If carefully stored, so that they do not crack or warp, horns can be collected and sold for manufacture into buttons, knife handles and tourist artefacts.

Rural Use of Offal.

Where it is impracticable to establish a by-products plant much can be done to avoid wastage of offal and convert it for local use.

Bone Meal

The organic matter of bones contains slightly more than 32% calcium and a little more than 16% phosphorus. Both are invaluable supplements for feeding to livestock. Bones can be sterilized by burning which also deprives them of all organic matter leaving the mineral components in a friable form which can easily be pulverized. Although black, like charcoal, this bone powder is equal in feeding value to the best steamed bone meal obtained from commercial plants. Bones can be fired by stacking them on a metal frame over an open fire. Bones intended for sale to by-product plants can be piled in large heaps, exposed to the elements and then crushed with a stone crusher. The loss of weight due to exposure saves freight charges but the practice is best suited to arid environments with sparse human populations where the bones dry quickly and their presence is unlikely to be offensive to the community. Air-dried and fire-dried bones account for approximately two-thirds and one-third of the fresh bone weight, respectively.

Blood

Blood is a particularly difficult component to deal with. It clogs drains, attracts vermin, has a very poor keeping quality and, if infected, it is a very dangerous carrier of disease. However, it is a valuable feed source of high quality protein. Blood can be prepared locally, on a small scale for stockfeed using the following methods:

(1) *Absorption*. The blood is mixed with locally grown carbohydrate-rich feeds such as bran, pollards, maize meal or cassava flour and the resulting dough spread out thinly on mats or trays to dry in the sun or from heat provided from some other source.

(2) *Treatment with lime*. The addition of approximately 1% unslaked lime or 3% slaked lime causes the blood to coagulate into a black, rubber-like mass. This makes it easier to handle and improves its keeping quality. The rubber-like mass can subsequently be broken up and dried.

(3) *Coagulation, pressing and drying*. Where large quantities of blood are available it is first of all advisable to cook the blood for 1520 minutes in order to sterilize and coagulate it. This expresses about half its water content. Further reduction of the water content can be achieved by putting the coagulated blood in a hessian bag and hanging it over a pole to drain or by pressing it between planks weighted with stones. The remaining mass can then be dried.

To ensure complete sterilization before blood is fed it is recommended that when it is mixed with a carbohydrate-rich feed it should be boiled.

Ruminal Contents

The contents of the rumen, reticulum and omasum can be dried and used to replace bran or pollards in poultry foods at amounts up to 10% of the total ration. Dried blood can be added to the dried material to improve the protein content.

Compost Making

After offal has been sterilized by boiling it can be added to vegetable waste to improve the value of a compost mixture. This practice makes good use of offals such as floor sweepings, blood, feathers, hair, urine, condemns, trimmings, etc. For a neat and clean stack the installation of a compost bunker next to the slaughterhouse is recommended.

Casings

The small intestines, particularly those of sheep and goats are in demand for use as sausage-skins, etc. A common method is to remove the intestines immediately the carcase has been eviscerated, and to strip off most of the surrounding fat. Where possible they should be put into cold water to arrest fermentation and harden the

remaining fat. Subsequently, the contents of the gut should be stripped out by pulling it with one hand between the fingers of the other. In order to loosen the different layers the stripped intestines are subjected to fermentation. This is followed by a sliming process whereby the mucous lining and remaining fat is removed by pressing a wooden or bone sliming knife along the intestines until only a thin, transparent, membrane is left. Care must be taken not to tear the casings. The ideal is an undamaged length of 2430 m for sheep or 2023 m for goats. Cleaned casings can be cured by rubbing them with fine salt and leaving them to drain and cure for about 2 weeks before shaking them out and coiling them for packing. Alternatively, they may be brined in a saturated salt solution and transported in wooden barrels, plastic containers or plastic-lined metal drums.

Waste Disposal

The disposal of effluent can be achieved successfully by simple methods provided: (a) it is not mixed with blood; (b) all solids are screened; and (c) the grease is trapped.

A simple but efficient use of effluent is for the irrigation of market gardens adjacent to abattoirs. Some soils do not readily absorb water and in this event, evaporation beds, alternately flooded and dried, can be used. Soakage pits, not less than 6 m deep and 1.8 m in diameter covered with a cement top are satisfactory for only the smallest units and only then after careful grease trapping and screening. Subsurface irrigation, consisting of herringbone trenches filled with stones, often gives excellent results, especially when trees capable of evaporating large volumes of water are planted alongside. An ever-present problem where waste disposal is concerned is the control of vermin, insects and carnivorous pets such as dogs and cats.

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20
Animal Fibres.

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Introduction

Fibres of some sort are produced by all domestic mammals, and they have long been used by man for clothing and blankets. In several species of animal, but most notably in sheep, fibre production has been greatly increased over the years by selection. Fibre production may be the primary aim of a livestock enterprise, or fibre may be a byproduct of meat production. Some characteristics of various fibres are summarized in Table 20.1.

This chapter briefly describes the various types of animal fibre, their production and use. It summarizes the basic biology of fibre production, methods of harvesting fibres, classification, improvement, problems of production, and world trade. In this chapter the term 'wool' is restricted to fine fibre produced by sheep, although some authors also use the term 'wool' for the fibres produced by llamoids and other animals. Another confusing term is 'yield'. In wool biology this is the ratio of clean fleece weight to greasy fleece weight, but for species other than sheep 'yield' is the annual production of fibre.

Types of Animal Fibre

Wool

There has been a vast amount of work on wool production reported in the scientific literature, and wool research in the tropics was comprehensively reviewed by Burns (1986). Wool sheep are found in highland areas in the tropics and in dry parts of the lowland tropics. There is almost no commercial production of wool in the humid tropics. A substantial proportion of sheep in the tropics do not produce wool; they are hair sheep and have coats similar to those of short-haired goats.

Wool has many uses, depending on its characteristics. Coarse wool, which is the most durable, is used for carpets, whereas fine wool is used for clothes. In the lowland tropics indigenous wool sheep have fleeces suitable for carpet manufacture. Examples are the Awassi in Western Asia, the Malpura and related strains in Rajasthan, India, and the Barki in Egypt. Some data on wool production of tropical sheep are summarized in Table 20.2.

In less developed tropical countries fine-wool Merino and related breeds of sheep are confined almost exclusively to cooler highland areas such as the Andes in South America, the East African highlands and the Himalayan region. In Australia only a small fraction of the total Australian sheep population is found north of the Tropic of Capricorn. Almost all are Merinos, but their wool is coarser and their productivity lower than those further south (Brown & Williams, 1970).

World production of wool is about 2.6 million t (FAO, 1996), of which about 0.7 million t is produced in developing countries, particularly China, Argentina, Uruguay, Pakistan, Algeria, Iran and India.

Mohair

Mohair is produced by Angora goats which originated in central Turkey and were introduced

Table 20.1 Characteristics of animal fibres. (*Sources*: various; see text.)

Animal	Fibre	Mean diameter (µm)	Mean length (cm)	Mean weighta (kg)
Tropical wool sheep	Wool	2666	419	0.93.5
Merino sheep, in tropical Australia	Wool	2028	812	1.42.3
Hair sheep	Hair	40100	15	
Angora goat	Mohair	2541	1525	2.55.6
Down goat	Cashmere	1119	68	0.20.7
Goat	Hair	40100	110	
Alpaca	Fibre	2240	815	1.5
Llama	Fibre	2850	2530	
Vicuña	Fibre	1020	35	
Bactrian camel	Hair	1555	2332	2.86.8
One-humped camel	Hair	20140	240	0.71.4
Buffalo	Hair	80107	17	
Rabbit	Angora	1115	410	0.20.4

a Greasy fleece weight of adult females.

Table 20.2 Wool production by tropical breeds of sheep. (*Source*: Burns, 1986.)

Breed	Location	Annual greasy fleece production of ewes (kg)	Mean fibre diameter (µm)
Arabi	Iraq	1.8	26
Awassi	Western Asia	2.0	35
Barki	Egypt	2.1	32
Chokla	India	2.1	28
Deccani	India		35
Hamdani	Iraq	2.0	30
Israeli Improved Awassi	Israel	2.7	
Jaisalmeri	India		36
Karadi	Iraq	1.6	39
Libyan Barbary	Libya	2.7	32
Magra	India	2.8	36
Malpura	India	1.1	42
Najdi	Saudi Arabia	2.2	66
Nali	India	1.9	37
Nilgiri	India	1.6	
Ossimi	Egypt	2.1	
Patanwadi	India	0.9	30
Sonadi	India		61

into South Africa and the United States during the nineteenth century. South Africa and the United States are now the major producers. Other producing countries are Turkey, Argentina, Lesotho, Australia and New Zealand. Recently, mohair herds have been established in several European countries, but production is limited.

Mohair fibres are smoother than wool fibres. The finest quality mohair, produced by kids and young goats, has a mean fibre diameter of 2532 µm and is used for fashion fabrics and fancy

yarns. Older goats produce coarser mohair which has a variety of uses including blending with wool (Van der Westhuysen, 1982). The most desirable length of fibre for processing is 1216 cm, so it is important to have a shearing interval that allows this length to accumulate. Common faults in Angora fleeces are the presence of hairs, uneven length and uneven diameter fibres, low density of fibres, lack of wave or spiral twist, coloured fibres and contamination with vegetable matter or string.

The production of mohair depends very much on feeding level; production is greater and the fibres coarser when nutrition is good (McGregor, 1996). Compared with other types of goat, the Angora appears to suffer more from nutritional stress, probably as a result of intensive selection for mohair production (Huston, 1982). Supplementary feeding not only increases mohair production but also reduces abortion which can be a serious problem in the breed in South Africa.

Cashmere

Cashmere or *pashmina* is the fine downy undercoat produced by several breeds of goats in Central Asia and certain other parts of the world. *Cashgora* is the fibre intermediate between cashmere and Angora; total world production of cashgora is small and largely restricted to New Zealand (Shelton, 1992).

The major areas of cashmere production are the mountainous regions of north and west China, Mongolia, Afghanistan and Iran. Goats which produce cashmere can withstand low levels of nutrition, but they have thick coats which would be disadvantageous in hot tropical areas. A brief description of cashmere is included in this chapter as there is interest in introducing cashmere goats into some tropical countries.

Cashmere is traditionally harvested by combing out fibres from the fleece as they are shed in the spring and by collecting fibres caught on bushes and trees. After collection the thick hair fibres are separated from the cashmere by hand. In modern commercial systems the fleece is shorn in early spring before the onset of the annual moult, and the hair subsequently removed mechanically. Mechanical dehairing is an expensive industrial process requiring large volumes to be cost-effective so that in the major producer countries the collection and marketing of cashmere fibre is centrally organized and usually administered by the state.

Cashmere is a very soft and fine fibre used for speciality ladies clothing, sweaters, scarves, stoles, etc. The average fibre length is short, because cashmere yarn is not very strong. Dark cashmere from China (mean diameter 1415 µm) is finer than light-coloured cashmere from Iran and Afghanistan (mean diameter 1819 µm). Most cashmere is dyed (Forte, 1982).

Unlike mohair, cashmere is a secondary product of goats which primarily produce meat or milk. Several Asian breeds of goats produce cashmere. The following were described by Mason (1981): Cashmere, Chungwei, Morghose, Vatani, Kaghani, White Himalayan, Chegu and Pashmina. Of the Chinese down breeds, the Liaoning is the most productive (Ying & Min, 1989). The Don breed in Russia produces large amounts of down, but it is coarser than cashmere from other sources. Millar (1986) reviewed the production characteristics of Asian and Soviet breeds.

Goat Hair

There is little information available in the scientific literature about goat hair. Although much goat hair is not utilized, the long hair of goats is traditionally used for the production of tents, ropes and bags, particularly in Asia. Together with the fibres of sheep and camels, pastoralists in Sahelian Africa use goat hair to make carpets and other household goods. Pakistan is the world's largest exporter of goat hair, and Ahmad (1967) reported that 80% was clipped from live goats, 17% from salted skins and 3% obtained from tanneries.

Fibres of South American Camelids

The alpaca is the most important species of South American camel for fibre production. It is

found largely in the high Andes in Peru and Bolivia where it is shorn annually or every other year, and produces brown, black or white fibres. The Suri alpaca produces longer, more desirable fibre than the more numerous Huacaya (Novoa, 1981). Problems of alpaca production are discussed in Chapter 12. White alpaca are said to be less disease resistant than coloured animals, but their fibre commands a higher price (Orlove, 1980).

The llama is the largest of the South American camelids. It is kept primarily for meat and pack purposes, and it produces coarse fibre which is used in the manufacture of local garments but is of little commercial value (Martinez *et al*., 1997). The vicuña is small and produces extremely fine fibre. Detailed information on the South American camelids is provided in Chapter 12.

Camel Hair

The one-humped camel is the most numerous type of camel and is found in Western and Southern Asia and in Africa. The Bactrian camel has two humps and is found only in Central Asia in cool dry climates. The Bactrian camel produces long hair which is woven into cloth and fine blankets. Samples from the shoulder of Sunita Mongolian camels comprised more than 90% fine hairs with diameter <25 µm (Shui & Wu, 1983). For the one-humped camel, wool and hair production are generally of only minor importance (Schwartz, 1992); in Saudi Arabia the hair is used for weaving blankets, rugs and wall hangings (Sohail, 1983), and in India there is some interest in blending camel hair with wool or polyester for cloth manufacture (Gupta, *et al*., 1989). Further information on camels is provided in Chapter 11.

Rabbit Angora.

The Angora breed of domestic rabbit thrives in temperate or sub-temperate conditions, and produces fine-quality fibre. Angora production is labour intensive and has developed in areas where labour is cheapin many parts of China and in the northern hills of India. World rabbit angora production has increased substantially in recent years. China is now by far the largest producer, producing about 6000 t/year.

Hair from Other Animals

Hair from cattle, buffaloes and pigs may be utilized. The tail and ear hair of cattle is obtained in the slaughterhouse, whereas body hair is a byproduct of the tanning industry. The hairs of water buffaloes are twice as thick as those of cattle, and as they are strong and flexible they are used to make fine brushes. In Bulgaria, buffalo hairs are harvested either by combing the animals in spring or from the hide-processing factory (Cockrill, 1974). The long stiff hairs from the back and tail of pigs, known as bristles, fetch a superior price to the body hair.

Fibre Production

Biology of Fibre Production

Hairs, wool and other fibres grow in follicles in the skin. The structure of follicles is described by Shelton (1981), Reis (1982) and Sumner & Bigham (1993) and in many physiology textbooks. In sheep and goats there are two types of follicle (Fig. 20.1). The primary follicles are the first to develop in the skin of the fetus. They are usually larger than the secondary follicles and produce coarser fibres except in some wool breeds of sheep. Primary follicles have associated sebaceous glands (which produce grease), sudiferous glands (which produce sweat) and erector muscles (which erect the hair in cold environments). Secondary follicles have sebaceous glands but not usually sweat glands or erector muscles.

All fibres are composed largely of the keratin proteins which contain a high proportion of sulphur. Thick fibres, usually called hairs, have a low density centre known as the medulla. Coarse wool fibres are also extensively medullated, whereas fine wool, mohair, cashmere and alpaca fibres are usually non-medullated. On the outer surface of each fibre there are scales which help

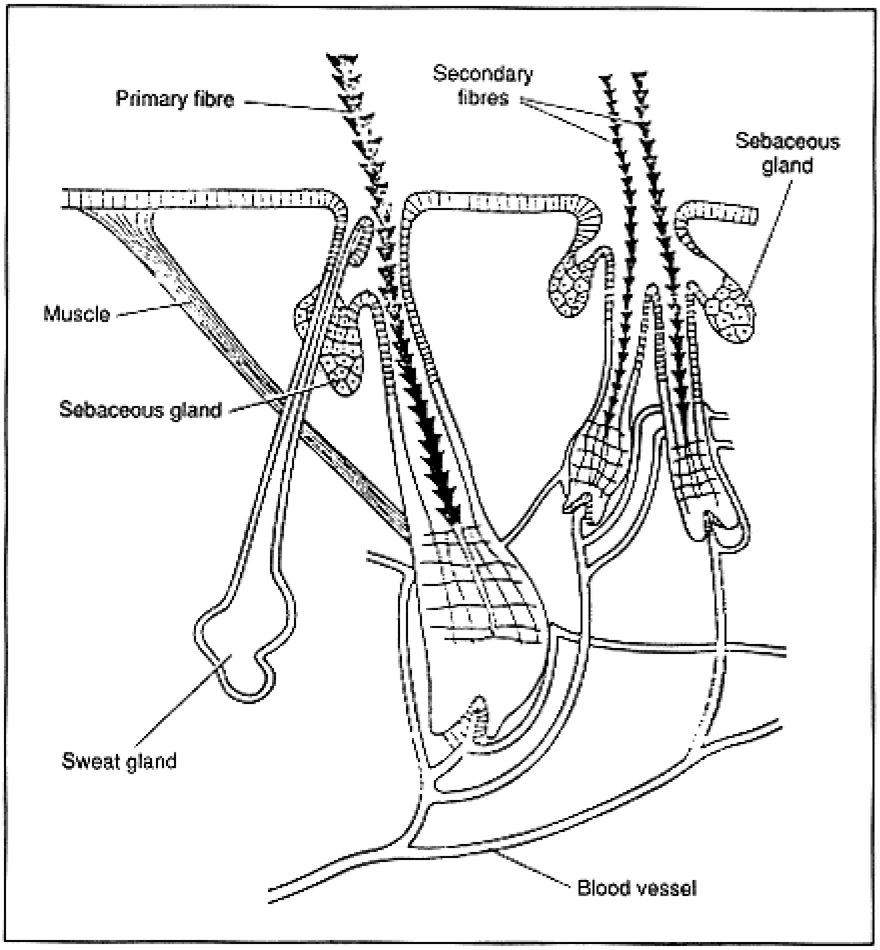

Fig. 20.1
Structure of skin and wool fibres.
(Source: Speedy, 1980.)

hold the fibres together during processing. Mohair has less pronounced scales than wool and looks more glossy.

The number of waves per unit length of fibre is known as the crimp frequency. It has long been believed that crimp frequency in Merinos is directly related to fibre fineness, but this correlation can be very low (Burns, 1986). Unlike wool, mohair does not have crimp.

Fibres do not grow continuously; there is a cycle of growth, follicle regression and resting. In most fibre-producing animals the cycles of all the follicles are synchronized and linked to seasonal influences to give an annual moult or shedding of fibres. In fleece-bearing sheep and goats, and especially in Merino sheep, seasonal moulting has been reduced to the shedding of a few scattered fibres, and the majority of fibres probably have such prolonged growth cycles that they exceed the lifetime of the animal.

Factors Affecting Fibre Production

Many factors influence fibre production. The most important are the genotype of the animal and its age and nutritional status. Other factors are physiological status, disease, thermal stress and shearing regime.

The ratio of the number of secondary to primary fibres (S/P) and their diameters determines the nature of the coat. Some values of the S/P ratio are summarized in Table 20.3: the S/P is between 11 and 46 in Merino sheep, 914 in cashmere goats, 612 in Angora goats, 4.2 in Awassi sheep and 1.8 in the coarse-woolled Indian sheep breeds Jaisalmeri, Malpura and Marwari.

As an animal grows, its total number of follicles remain almost constant so that fibre density (number of fibres per unit area of skin) decreases with age. Values of fibre density in adult farm animals vary from 1 to 4 per mm2 for the water buffalo to 25120 per mm2 for Australian Merino sheep. The density of primary follicles is relatively similar for all breeds of sheep and goats (Sumner & Bigham, 1993), and the differences in total follicle density between breeds are due mostly to their differing S/P ratios.

Fibre length growth increases with age until adulthood and the fibres produced by young animals are thinner than those from older animals. Thus the finest quality fibres are obtained from young animals.

Inadequate nutrition can cause some follicles to produce very fine weak fibres or even to cease production. Fibre growth must compete with other physiological processes for the use of available nutrients. There is a positive relationship between fibre growth and feed intake in sheep and Angora goats (Sumner & Bigham, 1993). On the other hand, cashmere growth appears to be relatively insensitive to nutrition under normal grazing conditions. There is generally a linear relationship between wool growth and feed intake (Langlands & Donald, 1977). Changes in wool growth due to changes in feeding level are associated with equivalent changes in fibre length growth and mean fibre diameter. Controlled low plane feeding of fine-wool Merino wethers has been used to produce superfine wool.

The keratin of wool and other fibres has a particularly high content of sulphur-containing amino acids, so that dietary requirements for protein and sulphur are high in fibre-producing animals. Many supplementary feeds may supply enough nitrogen for fibre growth, but not enough sulphur. The effects of sulphur deficiency on sheep and goats were reviewed by Qi *et al*. (1994) who concluded that practical methods of overcoming the problem of sulphur deficiency are:

(1) Dietary supplementation with inorganic sulphur to meet the requirements of ruminal microorganisms.

(2) Dietary supplementation with ruminal escape protein or ruminally protected sulphur-containing amino acids.

(3) Sulphur fertilization of grassland.

Wool growth decreases during pregnancy and lactation, indicating a higher relative demand for nutrients for reproduction than wool growth. If the fetus or young animal is subjected to severe undernutrition the development of secondary follicles may be depressed and the potential S/P

Table 20.3 Density of follicles and ratio of secondary to primary (S/P) fibres for adult animals.

Animal	Fibre	Density of follicles/mm2	S/P ratio	Source
Tropical wool sheep	Wool	15	1.84.2	Narayan, 1960; Bhatnagar *et al*., 1975
Merino sheep, in tropical Australia	Wool	25120	1146	Carter & Clarke, 1957
Hair sheep	Hair	815	<4	Burns, 1967a
Angora goat	Mohair	25	612	Devendra & Burns, 1983
Down goat	Cashmere	3060	914	Yongjun *et al*., 1996
Goat	Hair	520	35	Burns, 1965
Bactrian camel	Hair	1740		Shui & Wu, 1983
Buffaloes	Hair	14		Cockrill, 1974

ratio reduced, leading to a coarser fleece. Follicle development can also be impaired by certain diseases or severe heat stress (Sumner & Bigham, 1993).

There is some evidence that wool growth is depressed after shearing. This can be attributed to the use of limited dietary protein as an energy source in a cool environment. The effect of shearing on body weight is often more substantialshearing reduces weight growth in a cold environment and in a hot radiant environment, and it may increase weight growth in a hot humid environment.

Harvesting Fibres

Most fibres are harvested from the animal in one of two ways: by shearing the animal at intervals or by removing the fibre from the skins of dead animals in the abattoir or tannery. Cashmere is also harvested by a third methodcombing out the undercoat. Traditionally sheep and goats are clipped with hand shears or, in Western Asia, shorn with a knife, but in modern commercial units they are shorn with electrically powered hand clippers. In Australia the cost of shearing is the largest annual expense of sheep production, and there is interest in developing cheaper methods of wool harvesting (Mackenzie, 1988). Research is being undertaken into automated mechanical shearing, improvements to traditional shearing and biological defleecing by dosing the sheep with a chemical which causes a temporary thinning in the wool fibres so that about 2 weeks after treatment the fleece can be removed by hand (Fahmy & Moride, 1984). Several practical problems remain, however, and chemical defleecing is not yet recommended for commercial use.

The shearing interval depends on the length of fibre desired, the growth rate of the fibre and the amount of contamination in a long fleece. In most parts of the world sheep are shorn annually, although in India they are normally shorn every 6 months. Angora goats are also shorn every 6 months, and rabbit angora is usually harvested every 3 months. The shearing interval of llamoids is often 2 or more years. Care must be taken to ensure that in cool climates the newly shorn animals are not thermally stressed if the weather is cold and wet. Shelter or housing may be needed for a few weeks after shearing.

Classification of Fibres

Classification or grading of fibres is needed because there is variability between and within fleeces. If the fibre is used in local industries there may be no need for an official classification scheme, but if fibres are bought and sold, some description of quality is convenient. For instance, in Australia where the majority of wool is sold by auction, a sample is taken to determine average fibre diameter, percentage clean yield and vegetable contamination.

The fineness of wool is often described by its quality count, originally defined as the number of hanks of yarn 560 yards long which could be spun from one pound of wool. The four commonly used categories of wool, together with their typical fibre diameters and quality counts are detailed in Table 20.4.

South African mohair is classified according to fibre diameter (International Mohair Association, 1996, pers. comm.). Three of the categories are: average kid 2930 µm, average young goat 3334 µm and average adult 3738 µm. Further measurable characteristics of mohair and cashmere are reviewed by Lupton (1992).

Introduction and Improvement of Fibre Production

Fibre-producing animals can be introduced into an area either by the importation of a number

Table 20.4 Fibre diameter ranges of wool fibres and approximate quality counts. (*Source*: Onions, 1962.)

Wool type	Fibre diameter (µm)	Bradford Quality count
Merino	1824	80s60s
Crossbred	2530	60s48s
Lustre	3045	48s36s

longwool		
Carpet	4050	40s30s

of male and female animals, or by crossing indigenous females with fibre-producing males, possibly using artificial insemination. Another possibility, embryo transfer, may be useful in exceptional circumstances (see Chapter 4).

In the past fine-wool breeds of sheep have been introduced into many parts of the tropics such as Indonesia (Merkens & Soemirat, 1926), Nigeria (Burns, 1967a) and Mali (Wilson, 1981). These introductions resulted in the successful establishment of fine-wool flocks in some highland areas, but most introductions to the lowland tropics have died out or resulted in only a very small change in the native genotype. Similarly there have been attempts to introduce Angora and cashmere goats into the tropics.

The problem of importing females can be overcome by introducing males (or frozen semen) and crossing with local females. Backcrossing the crossbred progeny with the imported males is known as upgrading. The mean fibre diameters for the parental stock and three generations of crossbreds when longhaired Gaddi goats in India were crossed with Angora bucks are shown in Fig. 20.2. In the case of the females, the first and second generations with 75% or less Angora inheritance were inferior to the purebred Angoras, but the third generation had a mean fibre diameter of 25 µm, similar to the pure Angoras. The fibre length of the later generations of crossbreds was similar to that of the Angoras (Pant, 1968).

In Madagascar the crossing of hair females with Angora males and subsequent backcrossing produced mohair fibres as long as those from Angora in South Africa (Guillermo, 1949). In a report 20 years later concerning the continued crossbreeding programme in Madagascar, Lemaitre (1969) stated that although the third generation backcross looked like a purebred Angora and had a fleece weight of 4 kg, the quality of the fleece was inferior.

Burns (1967a,b) described the crossing of Uda and Yankasa hair sheep in northern Nigeria with South African Merinos. The first generation crossbreds had short fleeces with an S/P ratio of 8 compared with only 4 for the hair breeds. However, the Merino crossbred fleeces had too many kemps (thick fibres) for commercial acceptance. Crossing the hair breeds with

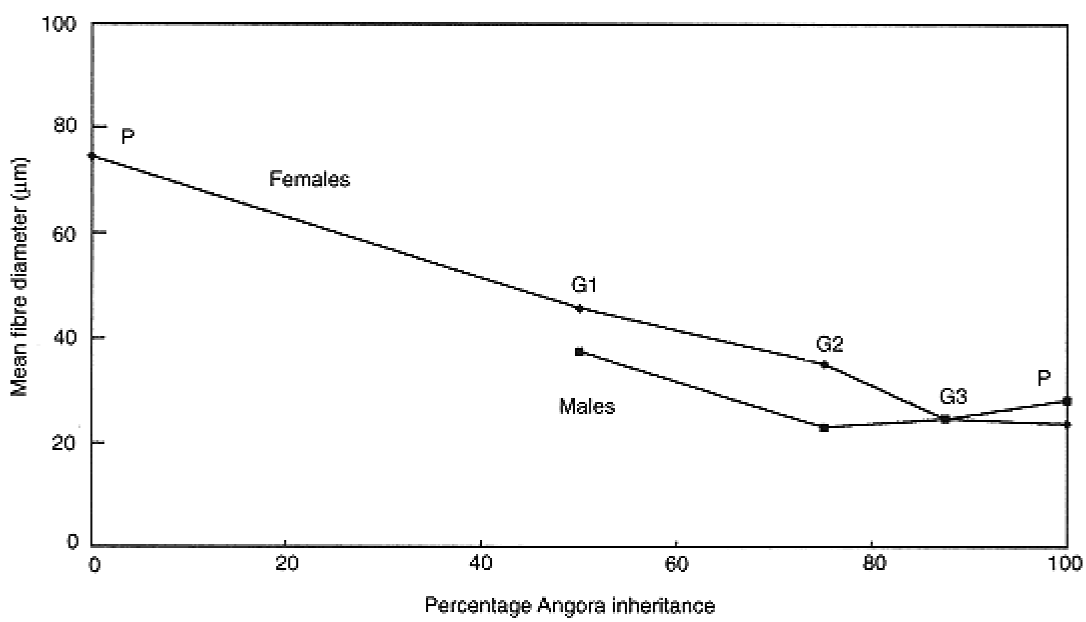

Fig. 20.2
Fibre diameter of Gaddi, Angora and crossbred goats in India. (P = parents; G1, G2, G3 = first, second and third generations.)
(Source: Pant & Kapri, 1968.)

Wensleydale rams completely eliminated kemp in the crossbreds, although some fleeces contained long medullated fibres. Some physical and chemical properties of wool samples from this project were described by Kazmi & Mathieson (1976).

In Egypt the coarse-wool Barki breed has been crossed with the Merino in an attempt to improve wool production. Guirgis (1980) reported that increasing the proportion of Merino inheritance from 25 to 75% resulted in increased greasy fleece weight, increased staple length, decreased fibre diameter and decreased percentage of medullated fibres.

In India there has been much effort coordinated in a national plan to improve the wool quality of native coarse-wool sheep by crossbreeding with imported fine-wool breeds. Reports from research stations indicate that crossbreeding reduces fibre diameter and has some effect on increasing fleece weight (Table 20.5). Although the reasonably high heritability estimates of wool and other fibre traits indicate that it is technically possible to improve the quantity and quality of fibre production, animals producing large quantities of high-quality fibre find it difficult to thrive in the lowland tropics (Sharma *et al*., 1994). The reproductive rate of exotic crossbreds is generally lower than that of purebred local animals and management must be of an extremely high standard if the envisaged fibre production is to be realized on commercial farms.

In addition, the objective of improvement must be closely examined. Where the objective is the increased production of carpet wool, the choice of the Merino is probably unwise. Burns (1986) commented that Merino wool lacks resilience and the high S/P ratio of the Merino is neither necessary nor desirable in carpet wool. She suggested that the Hamdani and Karadi breeds of Western Asia might be more useful to increase fibre length in Indian breeds, or the Nilgiri breed to introduce fineness plus medullation.

Problems Especially Associated with Fibre Production in the Tropics

Fibre-producing animals in the tropics suffer from the widespread problems of poor nutrition coupled with heat stress, diseases, internal parasites (particularly helminthiasis) and external parasites (mange in goats, lice in sheep). In addition there are some problems specifically associated with fibre production: bacterial growth, blowfly, weathering of the fleece and vegetable contamination.

Bacterial problems have been reported in many wool-producing areas of the tropics; these are most often observed for animals with dense fleeces in hot humid climates. In India a condition known as 'Canary Colouring' affects about one-third of all wool produced (Acharya *et al*., 1980). The yellow colour cannot be removed by scouring and it reduces the tensile strength of the fibres so that the value of the wool is reduced. It is associated with a high pH in the fleece; washing the sheep removes the alkaline suint which is the residue of sweat, and reduces the extent of canary colouring. In South Africa, bacterial retardation of wool growth has been reported for Merino rams on a high-quality diet (Jansen & Hayes, 1983). The fleece becomes yellow and sticky,

Table 20.5 Fibre diameter and fleece weight of Gaddi and crossbred ewes in India. (*Source*: Arora & Batta, 1983.)

	Mean fibre diameter (μm)	Six-month greasy fleece weight (kg)
Gaddi	28.3	0.50
Gaddi × Soviet Merino	23.7	0.68
Gaddi × Rambouillet	21.0	0.58

there are skin lesions and wool production is poor. In the wetter parts of Australia two bacterial problems are recognizedfleece rot resulting from a mixed bacterial dermatitis caused largely by *Pseudomonas aeruginosa* and *P. maltophilia*, and lumpy wool disease in which *Dermatophilus congolensis* causes an exudative dermatitis characterized by thick scab formation (Edelsten *et al*., 1990). Both these conditions are amenable to control by breeding (Adams, 1995).

Blowfly strike or myiasis occurs when the fleece is wet as a result of fleece rot or contamination with urine or faeces. The flies lay eggs which hatch within a few hours or days into maggots which eat the flesh of the animal. There are a number of flies which are a problem, but the most common are *Lucilia* spp. Blowfly strike can be reduced by mulesing (surgical reduction of skin folds and hence wool around the anus.) or docking (removing the tail), and by dipping or spraying with insecticides, although some species of fly are now resistant to many insecticides (Watts *et al*., 1979).

Exposure of the fleece to a hot sunny environment can damage the tips of the wool fibres. Venter & Edwards (1977) concluded that in South Africa the degree of weathering depends on the duration of sunshine and maximum daily temperature. It is possible to reduce this weathering by providing shade for the sheep.

Trade in Animal Fibres.

A summary of world trade in animal fibres in 1995 is given in Table 20.6. Wool production and trade greatly exceeded that of all other animal fibres. The wool export market was dominated by Australia and New Zealand. Secondary exporters were Argentina, South Africa and the United Kingdom. The major importing countries were China, Japan and several European countries, notably Italy, the United Kingdom, Germany and France (FAO, 1996). As wool is of various quality grades, some net exporting countries also import wool. For example, the United Kingdom imports fine wool even though it is a major producer and exporter of coarse wool. Some countries, such as Hong Kong, are negligible producers of wool, but have substantial trade and processing industries.

Since the 1960s there has been a substantial increase in the production of man-made fibres. Of the 42 million t total world fibre production in 1994, 50% was man-made fibres, 45% was cotton and less than 4% was wool (IWS, 1996). When wool breeds of sheep were developed in previous centuries in Europe and other parts of the world, wool was generally the primary output from sheep, but today in Europe and most less developed countries income from the sale of wool is low compared with income from the sale of meat

Table 20.6 World trade in animal fibres. (*Sources:* various including FAO, 1996.)

Fibre	World production (t/y)	Price (US$/kg)	Major exporting countries	Major importing countries
Wool	2 600 000	115	Australia, New Zealand	China, Japan, Italy
Mohair	11 000	1030	South Africa, United States	United Kingdom, Italy, Germany
Cashmere	6 000	50100	China, Iran, Afghanistan	United Kingdom, United States, Japan
Camel hair	3 000	1520	China, Mongolia	
Alpaca fibre	4 000	2025	Peru, Bolivia	
Vicuña fibre	50	200300	Peru, Chile	
Rabbit angora	10 000	3040	China, France, Germany	Italy

or milk. The supply response for wool is very inelastic, indicating that production responds very little to changes in price. World stockpiles of wool reached a peak in about 1990, but have subsequently declined because of suspension of the price support schemes for wool in Australia and New Zealand, which has led to reduced sheep numbers, and a reduction in wool production worldwide (Fig. 20.3). Production in developing countries has, however, shown a steady rise since 1960.

The wool trade and wool prices fluctuate widely. For example, the average United Kingdom market price for British greasy wool in 1994 was only £0.85/kg, rose dramatically to peak at £1.31/kg in March 1995 and subsequently declined. The reasons for the fluctuations are several. China, which is the largest user of wool, consuming 2030% of world production, is reforming its wool marketing system and purchases wool sporadically. Currently (in the late 1990s) in Japan demand is reduced as the economy is relatively depressed. However, there is new demand from carpet manufacturers in India and Nepal, and the expanding economies of South America are likely to be associated with increased wool imports.

Compared with wool, the quantities of other animal fibres are small and the prices higher. Even the production of mohair is less than 1% of wool production. World production of mohair rose in the 1950s and reached a peak in 1965. Between 1965 and 1975 production fell substantially from 30 200 to 13 200 t as a result of reduced demand and falling prices. Subsequently production rose again, reaching 26 000 t in 1988, but then fell steadily to an estimated 11 000 t in 1996 (International Mohair Association, 1996, pers.comm.). Unlike sheep and cashmere goat producers, Angora goat producers depend largely on the sale of fibre for income. The industrial demand for mohair is very variable depending on current fashion. In the past Europe was the major processing area for mohair, and more recently India and the former Russia were major importers (Shelton, 1992). World production is still high relative to demand which has resulted in difficult trading conditions and poor profitability for producers (Laker, 1996). In South Africa which accounts for 45% of world production, the

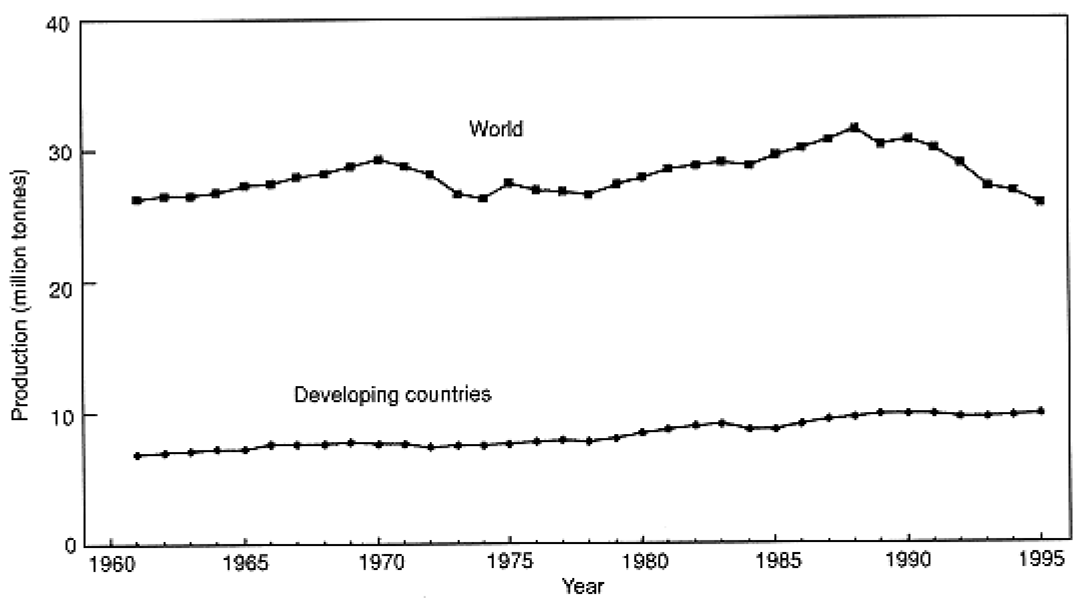

Fig. 20.3
Trends in production of wool.
(Source: FAO, 1996.)

profitability of mohair is currently low and producers have been switching to ostrich farming.

World production of cashmere is about 6000 t. China produced 60% of world output and other major suppliers were Iran, Afghanistan, Mongolia and the former USSR. Since 1970, cashmere production has been developed in Australia, New Zealand, the United Kingdom and the United States, but these together represent only 9% of total world production. Between 1965 and 1985 world prices of cashmere rose dramatically. Today, at the end of the twentieth century, there is a stable market for quality cashmere garments, but the price of raw cashmere is subject to large variations caused primarily by variations in the availability of cashmere from China.

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21
Work-Animal Power

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Introduction

When an animal uses energy to pull or carry loads over distances then it produces work. Agriculturalists, however, when considering 'work' as a product of livestock, regard it as any exercise which causes the animal to increase its energy expenditure above maintenance needs. Thus for animals as well as pulling loads and lifting them against gravity (true work), 'work' also includes energy used for moving, and for carrying a load, usually at a walk for ruminants, and walk and trot for equids.

Working animals have been used for centuries to assist farmers in the production, harvesting and marketing of crops and to provide transport. In the tropics, despite the development of motor power, animals continue to provide a major proportion of the power in agriculture. Tractors require foreign exchange for their purchase. They also require a ready supply of spare parts, expertise to maintain them and petroleum fuels to run them. Animal power, on the other hand, can be purchased with local currency, can reproduce and requires little specialist knowledge to operate. Animal power runs on locally available 'fuel' in the form of animal feedstuffs. It is not surprising that 80% of the power input on farms in developing countries is still provided by humans and their animals. On steep slopes and terraced fields, inaccessible to tractors, and on farms where size and scale of enterprise as well as finance rule out motor power, animal power is the only means the farmers have of cropping land, other than by the use of manual labour.

The Use of Animal Power in Agriculture

In crop production working animals are most commonly used for clearing the land, and to prepare a seedbed for sowing or planting the crops. Ploughs (mouldboards, which invert the soil, and ards, which do not), harrows, levellers, scarifiers, ridgers, rippers and/or rollers are all types of animal-drawn implements that can be used in land preparation. The actual techniques used by a farmer with work animals depend on the soil type, slope of the land and crop being produced. In the light sandy soils of Niger, for example, ploughing is often not necessary and a single-tine implement may be all that is needed to make a narrow furrow in which to plant the seed. In the heavier clay soils in the *fadamas* of northern Nigeria, for example, the land is more waterlogged with a heavy weed cover. Ploughing to invert the soil is essential in these conditions to aid soil aeration and drainage and to smother weeds before harrowing in order to make a smooth seedbed.

Using animals to pull a seeder/planter enables the farmers to plant more easily in rows. Row planting, whether by hand or by animal-drawn seeder, means that the farmers can also use animal-drawn equipment (tine cultivators or ridging implements) to weed between the rows. If seeds are sown by broadcasting then this makes it impossible to weed between the plants using animal power. Hence it makes good sense to encourage those farmers keeping working animals to plant their crops in rows.

Animals can be used when harvesting the crop to cart the crop and residues from the field to the store or threshing area. In many countries where cereal grains are grown, animals are used in the threshing process. They are driven around in circles over the freshly harvested crop to separate the grain from the straws. This practice is commonly seen where rice, wheat or barley are grown in mixed farming systems. Where grinding features in post-harvest crop processing, for example in millet and maize production, animals can be used to provide the power to operate the grinders.

Although working animals make their greatest contribution in crop production, they also have an important role in transport. Animal carts and/or sledges are used to move people and goods in rural areas especially where the roads are unsuitable for motor vehicles. Where wheeled vehicles cannot be used, such as in mountainous areas, and where roads are poorly developed or absent, pack animals may be used to transport goods. Working animals make a significant and often undervalued contribution to the marketing of the outputs from crop production. Animal pack and cart transport is used to convey the goods to market for sale. Nowhere is this more evident than in Ethiopia where much of the produce from the rural areas is taken to market in the urban areas by some five million donkeys.

Pack animals can reduce the drudgery involved in household activities such as water and firewood collection, and thus reduce the burden on women and children. Despite this benefit to the family, there are many areas where either for financial or social reasons working animals are not used in these domestic activities, although the animals are available on the farm.

Working animals can also be used to power stationary equipment such as water pumps, sugar cane crushers and grinding mills and to assist in timber extraction, earthmoving and road building.

Trends in the Use of Animal Power

Areas of Decreasing Use

North America, Europe and most of Asia, North Africa and Latin America are areas where working animals are part of the traditional way of cultivating the land. In these areas the use of working animals has declined. In North America and Europe the decline has been rapid since the 1930s and most farms are fully mechanized. In developing countries the decline has been more recent. Since the early 1980s tractor numbers have increased considerably in Asia. For example, from 1980 to 1990 there was a greater than 70% increase in the use of tractors in Korea, Vietnam, India, Thailand and Indonesia (Pryor, 1993).

Mechanical power should not always be thought of as replacing animal power completely on a farm. In many instances it is integrated into the agricultural system, alongside animal power. Mechanization has been a feature of large commercial farms in Africa and Latin America for years, but on smaller family farms the tendency is for farmers to compromise; those who can afford to do so use tractors, others use tractors along with animals. The tractor may be hired for the heavier tasks such as ploughing and farmers then use their own animals for secondary cultivation, seeding, weeding and harvesting the crop. This generally means that the difficult tasks get done quickly, but without the farmer having to invest in an expensive tractor. The farmer still has animal power to fall back on and money saved can be spent on other inputs or goods.

A change in availability of animal power can occur as a result of drought or disease outbreaks, when numbers of work animals decline and many farmers then have to resort to a higher percentage of manual labour. In Zimbabwe, for example, it has been suggested that shortages of animal power are a major constraint to increased productivity in the communal lands (Tembo, 1989).

Areas of Increasing Use

Areas where numbers of work animals are increasing in the tropics tend to be where human labour has predominated in agriculture, for example in much of sub-Saharan Africa, where in the past animal diseases prevented the keeping

of work oxen. Improvements in disease prevention and control measures have now extended the range within which cattle can be kept and the use of animal power to replace human power has become a possibility for many more farmers. Increases in population pressure resulting in a move away from shifting agriculture and pastoralism and into settled crop cultivation, and a desire of cultivators to raise farm output and reduce labour bottle-necks, are other factors which have encouraged farmers to adopt animal power to supplement family labour. Unlike the traditional areas where animal power has been used for centuries, in these areas it has only really been promoted to any great extent since the 1950s.

In plantation agriculture and forestry, which are often highly mechanized, work animals have been integrated into a mechanized system, rather than the other way about. Plantations around the world are increasingly finding that animal power can make economic sense. For example, Unilever have increased their use of buffalo and ox carts on their oil palm plantations in Colombia and Malaysia, while oxen are being considered for logging operations in new forestry plantations in Tanzania and Malawi. Animals can be usefully employed moving the product from the site of mechanical harvesting to the roadside for collection by a motor vehicle.

In some places in Africa and Asia where mechanization has been promoted, difficulties have been experienced in obtaining, servicing and running tractors. In these areas tractor 'graveyards' are not difficult to find and farmers have gone back to draught animal power, or human power.

Although the technology of animal power and motor power may be available within an area, other factors can restrict their use. Farmers may switch from one power source to another on their farms as economics dictate, particularly if they are farmers who rely on hiring or borrowing of animals in the cropping season rather than maintaining work animals themselves. Consequently the source of farm power may vary considerably on a farm when viewed over the long term.

Numbers of Animals Used for Work

It is impossible to obtain precise information on the number of animals used for work in the world. All the large domesticated animal species from the dog to the elephant have been used. Most countries maintain statistics on livestock numbers, but for ruminants they do not identify use for work separately from use for beef or milk. In many places the large ruminants are multi-purpose. The males are used for work when required but are ultimately sold for meat. Those females which are used for work may also produce some milk and a calf in addition to work. Manure, hides and hair are other outputs from draught animals. Approximate estimates of the number of animals of each species found in the world, and the proportion of these used for draught in developing countries are provided in Table 21.1.

Cattle (*Bos indicus, Bos taurus* and cross-breds) are by far the most numerous animals used for work in the world. They are found on many small farms in Asia, Africa and Latin America (Fig. 21.1). Water buffaloes (*Bubalus bubalis*) are the next most numerous working animals. They are mainly found in the wetter, more humid areas of the tropics. Equids tend to be favoured for transport because of their higher speed of travel compared to the ruminants. They are also widely used for cultivation in Latin America, North Africa and some of the mountainous areas of Asia (for example Pakistan, Tibet, Mongolia and China). Unlike the ruminants they rarely have a resale value as meat. Donkeys are important in semi-arid areas. Their cheapness is an advantage in these areas where cultivation can be a risky business with a high chance of crop failure. Their small size, however, generally restricts their use in agriculture to the lighter cultivation tasks, such as seeding and weeding, and transport. A donkey can very often be used by women to reduce their work load when collecting firewood or water, where socially a single horse or ox or a team of oxen would be unacceptable (Fielding & Pearson, 1991; Bakkoury & Prentis, 1994).

In the desert regions of Africa and Asia camels

Table 21.1 Estimates of the number of some of the large domesticated animals in the world in 1994 and the percentage of those in developing countries used for work.

Species	Developed world (million)	Developing world (million)	Percentage used for work in the developing world[a]
Cattle	450.4	920.6	51
Buffaloes	0.9	135.0	36
Horses	17.6	43.5	65
Donkeys	1.5	43.0	87
Camels	0.3	19.2	15
Mules	0.4	14.2	70

[a] Data do not include riding animals.

Fig. 21.1
Draught oxen working on a terrace in the Eastern Hills of Nepal.

are used in agriculture in addition to their use for transport. In Morocco, for example, it is not uncommon to see a donkey and camel working as a pair in land preparation. Scarcity and cost of camels has tended to be a deterrent to all but the more wealthy farmers, or those with specialized transport interests. Yaks and their crosses with cattle are used in the high altitude areas of China, Nepal, Tibet and Mongolia, the yak × cattle crossbreds being favoured for land preparation (Fig. 21.2) and the yak for pack transport. Llamas and alpacas are used in the Andes of South America, largely for pack transport, while migratory sheep and goat flocks in the Himalayas can still be found transporting salt from the Tibetan plateau to the valleys in the south. Estimates in the 1990s suggest there

Fig. 21.2
Yak × cattle crossbreds ploughing to prepare land for the planting of barley, at about 3000 m altitude in Lantang Valley, Nepal.

are about 17 000 elephants used for forestry operations in Asia.

Choice of Species or Breed.

It can be argued that there is a work animal for every environment from the cold high mountainous areas to the hot, humid lowlands. Climate and the prevalence of disease obviously influence the availability of species in a particular region. Choice of species is then largely determined by preference and finance. For example, in sub-Saharan Africa in particular, the donkey is often the first source of power the least wealthy farmer can afford other than family labour.

Where a choice of work animal is available, it is a case of balancing the advantages against the disadvantages of a species or breed, bearing in mind the use required of it, the resources available to maintain it and the climate and environment it is expected to work in. What suits one farmer in one situation does not necessarily suit another, in another region, carrying out different farm operations. The reader is referred to the chapters on the individual species elsewhere in this book for further information on breeds and types of animals used for work.

Outputs from Working Animals

Performance Parameters

Work, speed, draught force and power are the parameters that have been used to assess the output of working animals in the field. Work, speed and power are derived from the measured variables force, distance and time. The amount of work an animal can do will depend on the speed at which it works, and the draught force generated. As draught force increases, speed eventually decreases until the animal comes to a standstill (Fig. 21.3). For a particular draught force it is the speed which will determine the power output of the animal, i.e. the rate at

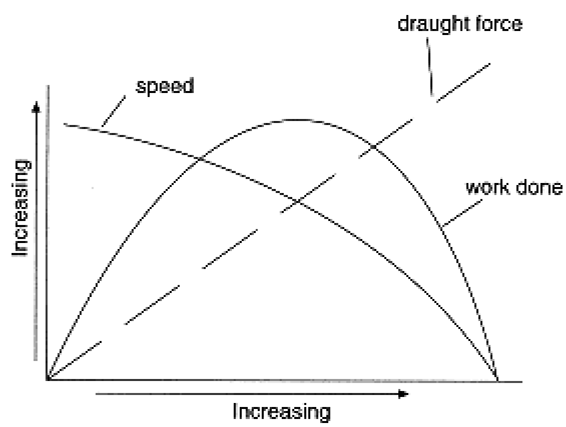

Fig. 21.3
Theoretical relationships between draught force, work done and distance travelled by a working animal.

which the animal does the work. Area ploughed during cultivation and distance travelled in transporting loads are other factors which can be measured, in the absence of the more sophisticated techniques needed to measure draught force and work done.

Factors Determining Work Done

Various aspects of the animal, the implement, the environment and the operator all interact to determine the amount of work done in a day. Some of the main influences are highlighted here:

• A large animal can sustain a higher draught force than a smaller one, but as draught force increases so speed decreases. An animal ploughing a heavy vertisol soil or a muddy rice paddy (high draught force) will walk more slowly than when it is pulling a well-balanced load in a cart over a level tarmac road (low draught force). Animals have their own preferred speed of walking. A pair of buffaloes or oxen pulling a lightly loaded cart will rarely go faster than 11.4 m/s even on a good road, whereas a small horse is likely to cover the ground at 1.5 m/s even when walking. Temperament also plays a part. Teams of animals of the same species of similar sizes carrying out the same tasks will do so at different speeds, a reflection both of the temperament of the animals and the person working them. Some animals are more excitable than others and some are lazier, just like their masters.

• Draught force is influenced by the type of implement being used as well as the soil type and depth and width of working in the soil. Some examples of the draught forces that have been measured on farms for various tillage practices are given in Table 21.2. The rolling resistance of a cart can be dramatically improved on sealed roads by replacing traditional wooden wheels with pneumatic tyres, reducing the draught force required to pull the cart and so enabling the animal to do more work in a given time. Sometimes the implement that is

Table 21.2 Typical average values for draught force required for some common agricultural tasks carried out by working animals. Values taken from actual field measurements.

Agricultural task	Implement	Soil type and previous crop, where known	Species	Average draught force (N)
Ploughing 14 cm depth	Mouldboard	Wet clay loam after maize	2 cattle	1300
Ploughing 10 cm	Mouldboard	Dry sandy loam soil after maize	2 cattle	700
Ploughing 12 cm	Ard plough	Wet loam soil after long fallow	2 cattle	1800
Ploughing 10 cm depth	Ard plough	Light dry soil after maize	2 cattle	300
Ploughing 14 cm	Maresha plough	Heavy soil after short fallow	2 cattle	950
Ploughing 14 cm	Mouldboard	Heavy sandy/clay soil	4 donkeys	1100
Ploughing 12 cm	Mouldboard	Sandy soil	4 donkeys	900
Ploughing 12 cm	Mouldboard	Red soil moderate	4 donkeys	800
Ploughing 14 cm	Mouldboard	Sandy loam soil	2 horses	1000
Ploughing paddy	Ard plough	Wet land	2 buffaloes	800
Harrowing	Disc harrow	Wet sandy loam	2 cattle	1200
Harrowing	Disc harrow	Dry sandy loam	2 cattle	850
Harrowing	Toothed harrow	Dry soil	2 cattle	800
Levelling	Indonesian leveller	Dry soil	2 buffaloes	360
Reduced tillage	Ripper tyne	Dry soil	2 cattle	1600
Ridging	Ridger	Dry soil, maize crop	2 cattle	1020
Ridging	Ridging plough	Wet loam soil	2 cattle	1400
Weeding	3-tyne duck-foot cultivator	Light soil	2 cattle	300
Weeding	3-tyne duck-foot cultivator	Heavy soil	2 cattle	760
Weeding	5-tyne cultivator	Sandy loam soil	2 cattle	1200
Weeding	3-tyne cultivator	Sandy soil	1 donkey	270
Seeding	Seeder + fertilizer		1 horse	450
Harvesting	Groundnut lifter	Sandy loam soil	2 cattle	600
Puddling rice field	Puddler	Flooded paddy	2 buffaloes	700
Carting	Pneumatic tyres	Sealed road	2 cattle	200
Carting	Wooden wheels	Farm tracks	2 buffaloes	350

available is not suitable for the task or the animal available. For instance, a small donkey is very unlikely to be able to generate enough force to pull an implement designed to be used by a pair of oxen for long enough to provide useful work in a day.

• Fairly accurate rules of thumb related to liveweight can be used when matching animals to implements: healthy well-fed oxen, buffaloes and light horses can exert a force equivalent to 1012% of liveweight continuously over a working day. Higher values are possible for camels (1214%), large draught horses and donkeys (up to 16%). This means that a 200 kg donkey could pull with a force of approximately 314 N and a pair of 450 kg draught oxen with a combined draught force of 971 N (1 N = 1 kg draught force × 9.81). Animals do produce draught forces that are higher than these values, but they are unlikely to be able to sustain them for the long periods necessary to accomplish a particular task without frequent rest periods and possible risk of injury. Obviously animals that are in poor body condition, underfed or sick will be incapable of producing as high average draught forces. Young and inexperienced animals may also perform less well.

• Adverse working conditions such as heat stress, a badly fitting harness, and difficult ground conditions such as slopes, stones or mud, will all reduce the rate of work and therefore the amount done in a day. Some examples of the performance of working animals measured in different environments when they were working for 56 hours a day are shown in Table 21.3. The data show just how variable the work done can be, depending on working practices, liveweight of the animal, task undertaken, implements used, ambient temperature and conditions underfoot.

With so many physical and social factors interacting to influence work done, it is not surprising that it is difficult to estimate how much of a field will be ploughed with a particular animal, how far a cart will go in a day with a particular load, or how many animals are needed to crop a particular area, although these are usually the facts that farmers and planners want to know.

Efficiency of Working

In order to do work a draught animal must expend energy. An animal obtains its energy from the food it eats. It is possible to measure how much food energy a working animal uses to accomplish a particular piece of work. This information can then be used to determine the efficiency with which the animal converted chemical energy into work. Buffaloes, on average, have a net energy efficiency of 0.31, zebu cattle 0.30 and donkeys 0.37. This looks favourable when compared with a tractor's efficiency of 0.250.33. However, animals also use energy for walking, and to maintain themselves. If these energy costs are considered, then the overall or gross efficiency drops, for example, to around 0.20 for an ox ploughing for 5 hours, less if it is expending a lot of energy walking over difficult ground, and even less (to less than 0.10) if the whole 24-hour period is taken into account.

Management of Animal Power

The management of work animals should include efficient management of the 'animal power' itself, both when it is required in seasonal tasks and over the rest of the year so that the resource is not wasted. Lending and borrowing and communal use of animals to ensure tasks

Table 21.3 Examples of the performance of animals working in pairs and estimates of their daily energy requirements (as a multiple of maintenance) when working under various production systems. (*Sources*: aBakrie & Ma'sum, 1993; bPearson *et al*., 1989; cBarton, 1987; dPerez *et al*., 1996; eBartholomew *et al*., 1995; fAlford, 1994; gLawrence, 1985; hPearson, 1989.)

Task	Animal type	Average liveweight per animal (kg)	Hours spent working	Location	Average speed of working (m/s)	Average power output (W)	Estimated energy expenditure as multiple of maintenance
Ploughing wet land	Buffaloes		4	Indonesia	0.50	290	1.241.37a
Ploughing dry land	Cattle		3	Indonesia	0.95	580	1.711.76a
Ploughing dry land	Cattle	250	5	Nepal	0.33	150	1.251.46b
Ploughing dry land	Cattle	150	34	Bangladesh	0.64	170	1.41.5c
Ploughing dry land	Cows	125	23	Bangladesh	0.61	125	1.3c
Ploughing rice field	Horses	530	6	Chile	1.39	1120	1.72.4d
Ridging	Cattle	300	45	Mali	0.74	590	1.44e
First weeding, millet	Cattle	260	45	Gambia	0.80	315	1.78f
Harrowing	Cattle	620	5	Costa Rica	1.10	900	1.61.8g

dry land							
Carting loads	Cattle	620	56	Costa Rica	1.03	210	1.61.8g
Carting loads	Buffaloes	400	56	Nepal	0.94	320	1.761.80h
Carting loads	Horses	650	8	Chile	1.6	570	1.862.40d

are completed at the right time are practices adopted by farmers to make the most of the animal power they have in an area. One way of optimizing the use of animal power is to encourage other uses for work animals. In areas where the work animal is unlikely to be replaced on farms, there is considerable potential for this. A reduction in the number of idle days in the year is a relatively easy way to increase efficiency of animal power on a farm. Unlike a tractor an animal needs 'fuel' irrespective of whether it is working or not.

Nutritional Requirements for Work

Since the mid-1980s, detailed reviews have been written on the nutrient requirements of ruminants for work (Lawrence, 1985; Teleni & Hogan, 1989; Lawrence & Zerbini, 1993; Pearson & Dijkman, 1994). Information on tropical equids and camels is also available (Wilson, 1984; Khanna, 1991; Pearson *et al*., in press).

Expressed in simple terms, the main nutritional requirements of working animals are for energy-yielding nutrients. Increased demand for protein in working animals may follow any tissue damage caused by sores or work injury, but the requirement is likely to be contained in the extra food needed to supply the animal's increased energy needs (Lawrence, 1985).

Work does not appear to change vitamin and mineral requirements greatly. However, an increased requirement for those minerals associated with the production of saliva and sweat (Cl^- and Na^+), when animals are working in hot environments is generally accepted. In some environments, particularly where the sodium content of the forage is low, it is a common practice to feed salt to working animals (about 200600 g/day).

Working animals have an increased requirement for water. The amount needed will depend on the duration of work and the climatic conditions prevailing. For example, the water intake of 300 kg oxen working for 5 hours per day in temperatures of about 30°C in Niger increased from about 23.7 litres/day to 31.5 litres/day (Fall *et al*., 1997b).

Energy Requirements

A factorial method can be used to estimate the net energy (NE) expenditure of working animals (Lawrence, 1985). In practice estimated NE used during work is equal to the energy used in the activities walking, carrying, pulling and/or that used in walking and carrying loads uphill (where required: for example, a pack animal will not use energy for pulling):

$$E = AFM + BFL + \frac{W}{C} + \frac{9.81(M + L)H}{D}$$

where E is the total energy expenditure for work (kJ), F is the distance travelled (km), M is the live mass (kg), L is the load carried (kg), W is the work done pulling (kJ), W can be replaced by F (distance travelled, km) × N (average draught force, N), H is the distance moved vertically upwards (m) and 9.81 is the acceleration due to gravity (m/s^2). A, B, C and D are the experimentally derived factors for the energy costs of walking, carrying, pulling and walking uphill:

*A*the energy cost of walking (J/m/kg) is affected by the ground surface the animal walks on. Values for cattle for example can vary from 1.5 J/m/kg on firm ground to 8.0 J/m/kg on waterlogged soil, and for donkeys can vary from 1.0 J/m/kg on firm ground to2.5 J/m/kg on sandy soils (Table 21.4). Assessment can be made subjectively based on ground conditions and depth of penetration of the animal's feet (Table 21.4).

*B*the energy for carrying is about 3.0 J/m travelled on a flat surface/kg load. An animal expends more energy in moving an applied load than it does in moving the same amount of liveweight. The movement of the load upsets the animal's gait and energy has to be expended in compensating activities. It is important to ensure that loads are equally balanced on each side of the animal's back and are well secured. This minimizes the energy cost of carrying the load. The energy for carrying can increase at least four-fold if the load is not well balanced.

Table 21.4 Predicted values for the energy costs of walking on different ground surfaces by cattle and donkeys. (*Sources*: a Lawrence & Pearson, 1998; Dijkman, 1992; Pearson, 1994.)

Ground surface	Ground penetration	Energy cost of walking (J/m/kg)a	
		Cattle	Donkeys
Smooth flat land, e.g. sealed road, dry unploughed soil.	None	1.5	0.9
Dry ploughed land and sandy soil or tracks	To top of hoof	2.5	1.4
Wet ploughed land and clay soils	Up to fetlock joint	5.0	3.5
Deep loose sand	Just over fetlock deep	6.0	
Waterlogged land	Above fetlock to knee deep, animal staggering	8.0	

*C*the net energy cost of work equals work done × 3.3, i.e. NE is used for work with a mechanical efficiency of 30%. It is affected very little by external factors such as species, rate of work, soil conditions, or ambient temperature. The main practical problem is that without specialized equipment, the work done cannot be directly measured. In most cases estimates of average draught force can be made if the type of implement or cart is known. For ploughing, information on soil type, previous crops and depth settings is also desirable. Total work done can then be estimated by multiplying the average draught force by the distance travelled (Lawrence & Pearson, 1998).

*D*the work animals do when raising themselves and any applied loads uphill is done with the same mechanical efficiency as work done pulling loads on flat surfaces. Net energy for going uphill is thus work done × 3.3 (Lawrence & Pearson, 1998).

NE costs for walking downhill are considered to be the same as for walking on the flat. Little experimental work has been done on this topic, but in general results indicate that the energy cost of walking down gentle slopes is less than that of walking on the flat, whereas the energy required for steep slopes is rather more.

Important observations have come from studies of work output and energy requirements of working cattle and buffaloes since the 1980s (reviewed by Pearson *et al*., 1996):

• NE used in work is often expressed as a multiple of 24 hours maintenance requirement, to allow comparisons to be made between animals of different weights. In the 1970s it was generally assumed that energy requirements of working animals were dependent on the type of work done. It was suggested that animals doing 'light', 'medium' and 'hard' work required energy equivalent to 1.5, 2.0 and 2.5 times maintenance requirements respectively (FAO, 1972). Determinations of the energy used for work by cattle and buffaloes in several tropical countries, carrying out a range of different tasks, have shown that this assumption is incorrect. Animals carrying out 'light' cultivation tasks or carting loads over firm level roads often expend more energy during a working day than when they are doing 'hard' work such as ploughing. This is because when doing 'hard' work such as ploughing an animal works at a slower rate and stops more often than when it is doing 'light' work. As a result the animal uses less energy in walking when doing 'heavy' work than when doing 'light' work and over the working day the total energy expended on work tends to balance out (Lawrence, 1985). Obviously an animal spending 2 hours a day working will have a lower energy requirement than one working for 6 hours a day, but the important point is that type of work does not have a major effect on total energy expenditure in a given time.

• Energy requirements for work are lower than predicted in the 1970s. Even when oxen are working for 67 hours a day their total energy expenditure for work is rarely over 2 × maintenance requirements, which is similar to requirements seen in beef or dairy cattle. Some examples of the estimated energy expenditures of working cattle and buffaloes carrying out different tasks in different locations are given in Table 21.3, alongside some performance parameters.

Information gathered on oxen and buffaloes has been used by Lawrence (1990) to produce tables predicting total energy requirements of work oxen, food intake and changes in liveweight, taking into account liveweight, quality of diet normally offered to working ruminants, the decrease in energy expenditure over the working day and the effect of work on resting metabolic rate. The tables (Lawrence & Pearson, 1998) can be universally applied where quantity and availability of food for work animals are known.

Less information is available for working equids in the tropics. Brody (1945) suggested maintenance requirements for draught horses in temperate countries should be increased by proportionately 0.10 for each hour of field work. Observations in Chile (Pérez *et al*., 1996) suggest that this may be an understatement when large working horses of 650 kg are carting loads, and values of up to 2.4 × maintenance have been estimated to reflect requirement more truly. Data on daily energy requirements of donkeys and small horses for work are scarce. Figures of 1.25 to 2.0 × maintenance have been suggested for working horses depending on whether the work is 'light', 'moderate' or 'intense'. This figure may be higher for the donkey, which is one of the most efficient of the domesticated animals in using chemical energy for work. It has a high work output in relation to liveweight, a low energy cost of walking compared to horses and ruminants, and apparently lower maintenance energy requirements than horses.

The Use of Female Animals for Work

Traditionally male animals are used for work in many tropical areas. Diminishing land and feed resources to maintain animals, however, has resulted in an increase in the use of female animals for work (Fig. 21.5). Cows are used for draught in Bangladesh, but to a lesser extent in India. Their use is increasing in Southern Africa and they are widely used in Southeast Asia. In Indonesia there are about 1.9 million draught cows. In the Philippines 24% of the draught cattle population and 75% of the 2.5 million buffaloes used for draught are female (Matthewman, 1987).

Although cows can be used for work there is a cost. In some areas where draught cows have been used for a considerable length of time, for example in parts of Indonesia, there is evidence that calving intervals are getting longer and there is a danger that supply of replacement milk and work animals will not meet demand. Liveweight loss in working female cattle and buffaloes can lead to reduced ovarian activity and longer calving intervals (Winugroho & Situmorang, 1989; Zerbini *et al*., 1993). This may be partly a nutritional effect as supplementary feeding can help alleviate the problem. Total milk yield can also decrease on working days (Matthewman *et al*., 1993).

If a cow is to work, produce a calf and produce a good supply of milk then it needs good

Fig. 21.4
A donkey used for ploughing in Niger.

management and good quality feed. This is not always available, hence most farmers recognizing they cannot feed sufficient nutrients to maintain the cow's liveweight often compromise. They accept they are unlikely to maintain milk yield and calving interval if they also require work from their cows.

Constraints to Work Output.

Provision of Feed

One of the most common problems farmers are faced with when keeping working animals is the provision of feed of sufficient quantity and quality at the time when the animals are required to do most work. The start of the cultivation season is usually the time when feed stocks are at their lowest, particularly when the dry season is long. Most systems make use of some of the following as staple feeds during the year: native grasses on permanent pasture, fallows and forested areas (on public land, communally owned land or on the farm), roadside grasses, crop residues remaining after the harvest and to a lesser extent agro-industrial by-products, tree fodder and browse. For much of the year working animals in the tropics consume poor quality forage diets that have a high cell wall content, low nitrogen content and poor digestibility. The metabolizable energy (ME) content of these diets is rarely higher than 9 MJ ME/kg (Parra & Escobar, 1985; Thahar & Mahyuddin, 1993; Topps & Oliver, 1993).

Intake and digestibility of these poor-quality diets can be low. Even when the animals are allowed to eat *ad libitum* it is unlikely that intake of the staple forage on working days will be enough to meet energy requirements for most types of work. Oxen, buffaloes and donkeys consuming high roughage diets do not tend to increase their intake of food to match their increased energy demands on a working day. When work occupies over 56 hours in the day, intake may even decrease, as the time available for eating and ruminating decreases. Effects of work on digestibility of feed are inconclusive. In the long term, when working animals are in regular work, some changes in intake may be seen. Over 3 months of regular, but intermittent work, a gradual increase in average weekly intake was seen in lactating cows (Zerbini *et al*., 1993), while steady increases in intake over time as animals adapt to work have been seen in oxen (Fall *et al*., 1997b) and donkeys (Nengomasha, 1998).

Any increases in rate of eating, or improvement in digestibility associated with work, are not sufficient to meet all the additional energy requirements for most types of work. In practice most farmers expect their animals to lose weight during the working season unless the diet is supplemented with better quality feed. When the quality of the food is very poor it is often better to have two animals doing what little they can, rather than one large animal.

Concentrate feed is the ideal supplement to the bulky basal diets, being a high density, readily available source of energy, easily consumed by the animal before and after work. However, concentrate feed is not always available and its cost may also preclude its use. Cheaper feedstuffs available locally may provide an alternative for the working animal.

Liveweight and Body Condition

The picture regarding the effect of body weight and, more especially, condition on performance is somewhat confusing. The larger the animal the higher the draught force it can generate. Theoretically this means that the larger the animal, regardless of body condition, the more easily it will carry out a specific task and the less stressed it will be. A large-framed animal may also be better able to respond to an increasing supply of food during a rainy season than a smaller, fatter one. Animals in good condition, however, have 'fuel' in reserve, which can be mobilized to make up any shortages in feed.

Despite the apparent benefits of having animals in good condition at the start of work, there is little conclusive evidence to show that animals in good body condition, score 6 or 7 on a scale from 1 to 9, work faster and/or longer than those in poor condition, score 3, (Nicholson and Butterworth, 1986). Nor is there evidence that crop yields are improved when oxen are given feed supplementation in the dry season. Studies in Mali (Bartholomew *et al*., 1994) and Niger (Fall *et al*., 1997a) confirmed that liveweight and not body condition is the main determinant of work capacity in oxen. Regardless of body condition the heavier animals did the greatest amount of work in the day. A similar conclusion was reached by Teleni (1993) studying village buffaloes in Asia. He suggested that weight loss in working buffaloes is not a problem provided that the critical weight for sustained draught load is not compromised that is about 1215% liveweight. The implications are to select large-framed animals for work purposes and feed them well during work.

In practice although they may show marked fluctuations in body weight and condition over the year, working animals are usually able to make up dry season and early cultivation season weight losses as grazing quality and browse improve over the rainy season and work demands decrease as crops are sown. Use of animals for transport, however, can extend the working season. The working animal may then have little or no off-season in which to replenish its body reserves. In this case some of the extra revenue obtained from working the animal all year (from transport, for instance) need to be set aside for supplementary feeding.

Clearly the economics of dry season feeding have to be considered in each area. While it may not be economic to carry out supplementary feeding in the dry season where work periods are short (2030 days), where animals work for longer periods the economic return of such a practice may be worthwhile.

Heat Stress

The oxidation of chemical energy to provide work produces heat which has to be dissipated if the animal is to continue to work and maintain homeostasis. While heat loss is not normally a problem if the animal is working in a cold or temperate environment, if the climate is hot, loss of heat by convection becomes less effective and the animal largely has to rely on evaporative losses through sweating and/or panting and drooling. Inability to dissipate the heat associated with work does limit the amount of work an animal can undertake in a hot climate.

The effects of heat stress on livestock are detailed in Chapter 1. Some are better able to work in hot climates than others. Where animals are required to work long hours at high ambient temperatures and humidities, it may be most advantageous in terms of work output to use indigenous animals.

Disease

Apart from working accidents and sores resulting from poor harnessing, a working animal will be prone to the same diseases as other animals of that species kept locally. Disease can lead to reduced food intake and poor physical condition which in turn lead to an increased susceptibility to diseases as well as severely reducing work capacity. Some efforts to prevent at least the acute diseases would seem to be economically justified by a farmer keeping working animals, whether it be by management, local medicines, vaccines or purchased drugs.

There is some evidence and much conjecture in the literature that the additional stress of work can predispose working animals to disease (Hoffmann & Dalgliesh, 1985; Wells 1986). The incidences of *Trypanosoma evansi* and haemorrhagic septicaemia have been observed to increase in buffaloes around the beginning of the work season, when animals are in poor condition and are further stressed by work. In Asia, Payne *et al* (1991) observed that although exercise did not appear to exacerbate the effect of *T. evansi*, the infection had a marked effect on body temperature and packed cell volume (PCV) profiles of infected buffaloes, both of which could adversely affect infected animals' work output and heat tolerance. Similarly, Clemence (1997) found that work output of buffaloes experimentally infected with *T. evansi* in Indonesia decreased as parasitaemias increased. In West Africa, trypanotolerance of N'Dama cattle seems to be reduced by work stress, both in experimentally challenged animals and those previously exposed to the disease. Work output is then reduced in association with increased parasitaemia and reduced PCV (Clemence, 1997).

Internal parasites are a problem in many areas. In Bangladesh, for example, most of the 20 million cattle and buffaloes suffer from severe internal parasites. There is considerable evidence that helminths (*Oestertagia, Haemonchus*, Trichostrongyles and *Fasciola*) can depress appetite and impair digestion and absorption and so in poorly fed animals they can exacerbate the effects of malnutrition. Helminth parasites are believed to be a major cause of unthriftiness and low life-expectancy of working donkeys in Africa (Panday *et al*., 1994). Anthelmintic treatment does seem to be associated with improved body condition, healthier or more active donkeys in several tropical areas (Fielding & Pearson, 1991; Bakkoury & Prentis, 1994).

A study by Samui & Hugh-Jones (1990) is one of the few attempts to quantify the financial and production losses due to disease in working animals. They conservatively estimated that the cost of working oxen being affected by bovine dermatophilosis in Zambia was US$193 per affected ox. This was based on loss due to reduction in area of land ploughed and loss of income from hire of the animals (Samui & Hugh-Jones, 1990).

The subclinical diseases may not kill the working animal, but can severely reduce its productivity and hence effectiveness in crop production and transport.

Yokes and Harnesses

Yoke galls and harness sores are some of the major causes of decreased work output. Losses are difficult to quantify as they do not generally prevent the animal from doing at least some work. The period of increased risk is at the start of the working season when animals have been rested for some time and the skin is soft at bearing surfaces.

In Africa a major problem in harnessing occurs when the cattle yoke is used on the donkey or horse. This is generally found in areas where cattle have been used, but donkeys are now becoming more popular. In this case the problem can be solved by 'transfer of technology' as simple harness systems for donkeys are available elsewhere in the world (Jones, 1991).

Improved harness design is often advocated as essential if working efficiency is to be improved, however in many cases improved designs are elaborate, costly and use materials that are not always readily available. Nor do they always show any marked improvement over traditional types in practice. Before attempting to introduce new types of harness the merits of the traditional types used within an area need to be studied. Time spent in considering better shaping of the yoke and extra padding to improve the fit of the traditional harness can make a remarkable difference to work output and is likely to be of more use than the introduction of a completely new system. If a yoke or harness fits comfortably on an animal, not only is the animal more kindly disposed to work and sores are less likely, but transfer of power from the animal to the implement may be improved.

Traditional materials such as leather, hemp and cotton used in harness are susceptible to rotting unless treated periodically with a preservative. Newer synthetic materials, increasingly being used in the industrialized countries as a substitute for leather in harnessing, are beginning to be used under tropical conditions. At present the problem with these materials is availability and cost.

Type of Implement

In areas of the world where work animals are traditionally used in agriculture, farmers have developed wooden implements, sometimes with metal attachments on the wearing surfaces. These implements are easily and cheaply obtained and easily repaired locally.

Metal implements are often found in areas of the world where animal power is a relatively new technology. The infrastructure is often not well-established locally to manufacture and repair the implements. Very often the metal has to be

imported, making the implements expensive, involving considerable investment by the farmer. Where metal is available locally it may be of an inferior quality making breakages and equipment failure common.

Cost and availability of implements can be a major constraint to the development of animal power in an area. In the past this has been exacerbated by the promotion of equipment packages, with the insistence that farmers need plough, cultivator and even a cart before they can get started. Not surprisingly uptake of animal power in this form has been low in many areas. More recently engineers have recognized this fact and simpler, cheaper implements have been investigated, often based on modification of local traditional implements in areas where they are available.

Development projects are also becoming more sensitive to farmers' attitudes. Now more projects are offering options and leaving the farmers to make a choice, rather than insisting on the acquisition of often inappropriate, expensive implements. As with the selection of type of animal it depends on what is suitable for the individual farmer, based on what is affordable and available. The risk element in crop production, farm income, availability of credit, type of work animal used, soil type and crops grown are all factors which will enter into the choice of implement(s) that a farmer will undertake to purchase. What suits one farmer does not necessarily suit another in the same area. In the traditional areas farmers tend to stay with what they know best, very much governed by cheapness and ready availability. In non-traditional areas choice of implement can be wide.

Changing Needs of Animal Powered Farmers

The world population is predicted to increase from 5.4 billion to about 10 billion within the first few decades of the twenty-first century, largely in developing countries. To feed this additional population, more land will need to be devoted to crops, consequently reducing the land available for pasture and fodder. This should mean that more crop residues and agro-industrial byproducts will become available for feeding livestock. Farmers keeping livestock in these cropping systems, where grazing land is becoming less available, will have to re-evaluate their feeding strategies and may have to adopt different feeding systems. In Africa the number of small ruminants has tended to increase as a proportion of the livestock as farm size and grazing areas have declined. That is except in those areas where animal power is used for cropping and transport. For example, Coe (1991) found that in the southern portion of the semi-arid zone and in most of the sub-humid zone of Senegal although population pressure is increasing, work oxen still dominate the livestock enterprise of mixed farmers. In areas where animal power has been a feature of mixed farming enterprises the strategies to overcome the reduced quantity and quality of grazing land have been to move to motorized power, or to modify animal husbandry practices.

In areas of South Asia which have high population pressures and are farmed intensively, such as Vietnam, Thailand and Malaysia, the reduction in grazing land has meant in many of the rice growing areas a change over from buffaloes to motorized power, in the form of two-wheeled power tillers and small tractors. On small farms of less than 3 ha, however, it is unlikely that animal power will disappear as it can compete economically with petrol-driven tractors under these conditions both in Asia (Campbell, 1993) and Africa (Panin, 1995). On farms where motorized power is not feasible many farmers are modifying their herd structure. The use of multipurpose animals for work, i.e. the farm cows and beef animals, removes the need to keep work oxen and hence saves on feed requirements. This is an increasingly common sight on animal powered farms, not just in Asia but also in Africa where the area of grazing land is declining. For example, surveys by several member countries of the Animal Traction Network for Eastern and Southern Africa (ATNESA) have shown a steady increase in the use of cows for work in many areas. Donkeys are increasingly being used instead of oxen for land preparation and cultivation in semi-arid sub-Saharan Africa (Fig. 21.4). They are easier to feed, and survive droughts better, than cattle. With the exception of places where it is culturally unacceptable to use cows for work, or cattle for meat, then the modern working ruminant is usually now truly multi-purpose, providing milk, and/or ultimately meat in addition to work and of course manure as fertilizer or fuel.

Farmers are having to modify their animal husbandry practices in the more intensively farmed and densely populated areas of Asia and Africa. In these areas animals are tending to be tethered or kraaled for longer, both for security and on account of the reduction in available grazing land. They are often fed on stored crop residues, collected fresh forage or purchased foods. Therefore more time is spent collecting and carrying food for the animals than previously in these farming systems. Greater reliance on crop residues and purchased high-quality feeds, for those that can afford them, and greater pressure on communally owned grazing resources have frequently been reported as systems become more intensive. Often greater reliance is also then placed on locally reared stock rather than those brought in from grazing systems.

A sufficiency of grazing land in the past has generally meant that work animals have been left to forage on rangelands, particularly out of season, and supervision of feeding has been

Fig. 21.5
A family of buffaloes owned by a landless contractor used for ploughing in the Mekong Delta, Vietnam.

minimal. The greater control that cut-and-carry methods of feeding can bring, can involve the farmers in more decision making. They can if they wish decide on the amount and type of feed that each class of livestock will receive at any one time. The farmers need sufficient information on the outcomes of this 'strategic' feeding to make best use of the farm feed resources. There are now considerable data available on the needs and consequences of feeding and good husbandry on the performance of work animals, to enable farmers to make informed decisions when managing these animals. This information can be used by local advisers to produce focused recommendations on husbandry practices for today's working animals.

Agricultural practices are closely linked with social traditions and cultures which are not readily modified. Any advances that are made on the research or development side may be adopted only slowly by the majority of small farmers who use animal power for agricultural production. If a farmer has a good market for his produce or revenue from transport then he is in a much better position to study options available than the farmer who is subsisting.

Whatever the outcome of innovations, promotions and new schemes for providing power in agriculture, it seems very likely that in the tropics working animals will continue to make a valuable contribution to the economy of smallholder farms and transport businesses for the foreseeable future.

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APPENDIX I
MARKING LIVESTOCK FOR IDENTIFICATION.

It is generally desirable that farmers and/or pastoralists should be able to identify each of the animals owned by them and often essential that they should be able to prove identification to the satisfaction of others. Marking obviates disputes over lost, stolen or strayed livestock. It is of course essential for all breeders to be able to identify their animals and for all those livestock farmers who keep records.

Livestock may be marked in a temporary manner or permanently. Temporary marking is required for heat detection, disease eradication, for culling purposes, etc., and can be achieved in a variety of ways, usually by use of a dyestuff, either dissolved in water or a fatty base, that will mark the coat of the animal for a longer or shorter period. Dyes are now marketed that will persist for several months. It is also possible to use a hair bleach solution for semi-permanent marking. Bleach marking will persist for up to 1 year.

The most common methods of permanent marking are by branding, tattooing, notching and tagging. Muffle prints can be used to identify cattle, but the method is cumbersome and its utility limited.

Branding

This is probably the oldest and certainly the most widely used method of identifying animals. A number, letter or design is seared on the skin or on an appendage using a hot iron, caustic soda or branding irons cooled to a very low temperature. Numbers are generally used to differentiate individual animals, but a design or a combination of letters may be used to denote membership of a specific herd. The symbols may be government registered.

The suitably fashioned iron is heated to a bright red, but not white heat, and is applied to the skin with light pressure for not more than 3 seconds. The numbers, letters or design should be sufficiently large to be read at some distance from the animal and each should be at least 2.5 cm apart from the other, in order to prevent sloughing.

The easiest and most visible place to apply the brand to cattle is on the upper aspect of the quarter, trunk or shoulder. However, in any of these positions a brand ruins a valuable part of the hide and for this reason branding should take place on the cheek, the forearm or the hind limb below the level of the stifle.

Cattle and buffaloes are often branded on the forearm, camels on the cheek and/or the neck.

The operation is unquestionably painful, and other methods of branding, apart from using a hot iron, have been attempted. Branding with the use of caustic soda is cumbersome, cannot be used in the humid tropics and is probably no more humane than hot-iron branding. The new method of 'freeze' branding is now widely advocated. Freeze-branding irons are usually made of solid brass and the coolant is usually liquid nitrogen or a mixture of ethyl alcohol and solid carbon dioxide. The brands are kept in the coolant and applied to the skin of the animal for between 15 and 30 seconds. Freeze branding gives very good identification, particularly on black-coated animals. The method is, however, very slow compared with the normal hot-iron branding, supplies of liquid nitrogen or carbon dioxide must be available and considerable care is needed during the operation. It is not recommended as a method for normal marking operations in the tropics, although it could be very useful on experimental farms, etc.

Branding can also be carried out on the insensitive horn or hoof of the animals with a branding iron of appropriate size. The disadvantage of this form of branding is that numbers on the horn can only be read on close inspection and that hoof brands grow out and distort very rapidly.

Tattooing

This operation has two drawbacks. First, the tattooed figures cannot be read without handling and close inspection of the animal, and secondly, tattoo marks are not easily legible on pigmented skin.

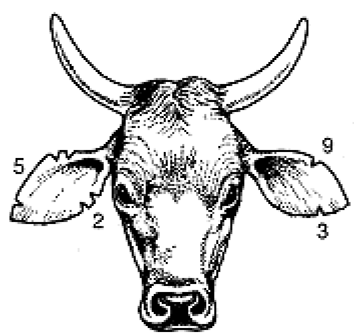
Special equipment is required. Tattoo imprints are most conveniently made on the inner side of the ear or they may be made on the undersurface of the root of the tail.

Tattooing is the most suitable method of marking young animals that are to be continuously handled and that can be marked for a second time, in some other manner, as adults. It is therefore widely used for marking piglets and young dairy calves.

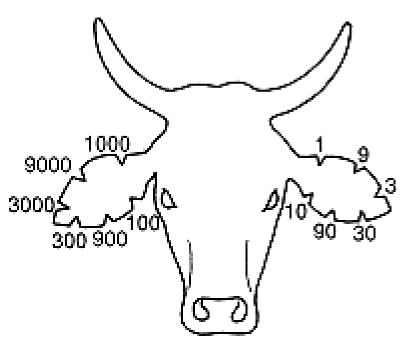
Unsatisfactory results are most commonly caused by dirty equipment, bad ink and misapplication of the equipment.

Notching

When properly carried out notching is a very satisfactory method of marking. The notches can, however, be easily changed so that fraud is relatively simple. Ear notching is practised on cattle, buffaloes, sheep, goats and pigs, but is probably most satisfactory when applied to pigs and to long-eared sheep and goats. A method that can be used for cattle is shown in Fig. AI.1.



Example: number 5239



A method enabling 9999 head of cattle to be marked

Fig. AI.1
A method of ear-notch identification
for cattle.

Notching, slitting or punching the edge of the web of the feet of poultry has been used as a method of marking in the past. It is not a very satisfactory method.

Notches in the ear are usually made with a pair of special pliers. Round holes, in the centre of the ear, can be made with a punch. It is of little use notching the ears of very young animals as the punched ears grow together again. Tattooing the ear of the very young animal and then ear-notching at weaning is a suitable combination of marking methods.

Tagging

Tags or labels made of metal, wood or plastic are either fixed in the ear of the animal or on some other appendage or they may be attached to chains or collars around the neck or the horns.

There is also a type of press-stud ear-tag. The number of different types available is now very large. In the past tags were only used by experimental stations but their use has spread to commercial holdings. Under intensive managerial conditions they are undoubtedly very useful, but they are not generally recommended for use under extensive bush conditions.

Wing Tagging or Banding

This is the most common and satisfactory method of marking and recognizing poultry. A light metal split ring, or a plastic tag that stands out from the wing, bearing a number, is inserted through a small slit made in the fold of the skin on the front edge of the wing opposite the elbow.

Leg Banding

This is another form of tagging used with poultry. The band is generally made of light metal and is just sufficiently large to slip over the foot. These bands are not easily read but they are easily lost.

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