SOIL ESSENTIALS

MANAGING YOUR FARM'S PRIMARY ASSET

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Strip cropping for erosion control (Photo: Bruce Carey)
Back cover
Left to right: Sulphur deficiency in white clover, wind erosion (Photo: Bruce Carey), stream bank erosion (Photo: Bruce Carey), strip cropping

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Preface

Australian soils can vary from the deepest, richest, most productive soils found anywhere, to some of the poorest soils globally. This is not unexpected on a land mass the size of Australia. The issue for farmers and land managers is how best to productively and sustainably manage the soils they are using. Past practices have not always been either productive or sustainable, and these practices came about mostly because early settlers and government departments did not properly understand the profound differences between the Australian soils and climate and those of Europe and the UK.

Over recent times, research into the management of Australian soils has led to a much better understanding of sustainable management at the same time as improving the soils' productive capacity. The achievement of these goals has required detailed study of the soil structure, chemistry and microbiology of a wide range of soil types and the climatic zones affecting the soils being studied. This research has been published as papers in scientific journals and in books, but has often been in a form that is not easy to translate into 'on farm practice'.

The other issue that every farmer is acutely aware of is the vastly more difficult economic climate in which they now operate, forced upon them by factors totally out of their control. To survive on the land these days requires a very high level of management skills, and quality support information from every source available. Gone are the days when a farmer could just guess at the correct fertilisers needed to grow a crop or to rely on information given by the local reseller. Nor can a farmer any longer get information from government departments of agriculture, as trained extension officers are also a thing of the past.

This means that farmers must use as much local knowledge as they can and, in the case of soils, use soil analytical testing much more than they did previously. One problem with this is the difficulty of interpreting the tests, as different laboratories may use different test methods, particularly from one state or territory of Australia to another. Some laboratories go to considerable trouble to provide sound recommendations as well as providing the analysis, while some may give the analysis, but no recommendations at all, instead relying on the fertiliser retailer to interpret the analysis and then do the right thing by the customer. *Caveat emptor*: let the buyer beware!

As understanding of soil chemistry and biology has improved, the importance of balancing soil nutrients, especially soil cations, has been realised and a few laboratories have specialist skills in this area. This book aims to safely guide the farmer through the minefield of soil structural, chemical and biological issues to help make sound decisions for producing crops economically and managing the soil for long-term sustainability.

Roger Hall
15 December 2007

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1

The nature of Australian soils

A soil consists of a mixture of sand, silt, clay and organic matter in varying proportions, which at first glance looks as if it should be reasonably easy to understand. When looking more closely at the make-up of fertile soil, it is seen to be a complex, ever-changing matrix supporting a complex living ecosystem.

The ecosystem consists of plants, which in turn support, and themselves depend on, a range of larger organisms such as insects, mites, spiders, earthworms and ants, not to mention livestock and other grazing animals. There are also small organisms including bacteria, fungi and actinomycetes, such as mycorrhiza, that are active in converting nutrients to plant available forms.

Fertile soil is dynamic and changes over time depending on moisture, temperature and the way it is managed.

It is true to say when farming soils, the production of crops and livestock is directly proportional to the microbiological content of the soil.

The origin of Australian soils

Soil is initially formed from weathering of bedrock, and the type of soil formed is determined by the type of rock that it is formed from. Obviously, there are large differences between rocks such as granite, basalt and limestone, and the soils formed from these rocks show large differences as well.

Water is one major factor in soil formation, transporting weathered rock from hills to valleys and depositing the rock particles initially on the slopes of the hills and later in layers in the valleys.

Air is the other major factor in soil formation, with wind carrying soil particles and depositing them often large distances from their original source.

For Australian soils there is a further major influence in soil formation: the fact that most of Australia has been under the sea at least once over eons of time. The immense pressure of deep water over the soil has turned old soil to rocks such as sandstone, siltstone and mudstone, and skeletons of marine organisms have formed limestone. When these rocks emerged from under the sea the erosion cycle started again, forming new soils from old. The salt content of Australian soils is largely due to the marine influence, but also wind-borne salt blown inland from ocean salt spray.

This very incomplete thumbnail sketch of the formation of our soils is enough information to enable an observer in a landscape to get a rough idea of where the soil they are standing on came from, and possibly a glimmering of the sometimes immense geological forces involved in making our landscape what it is today.

Past cataclysmic events such as volcanoes, land upheaval and massive rainfall events have also played a major part in forming our soils.

Effect of climate

Climate plays a major part in soil formation, chemistry, microbiology and structure.

Compared to cooler, moister, European conditions, our soils have to contend with much harsher effects. Remembering that fertile soils have a large living component, periods of hot dry summer conditions and cold wet winter conditions drastically change the quantity and species composition of living soil organisms. Many of the micro-organisms cannot thrive in hot dry conditions, and go into survival mode until soil temperature and moisture become more favourable. This is in contrast to European conditions when soil organisms often thrive throughout the year.

Waterlogged soil, on the other hand, has the effect of favouring some types of organisms, thus changing the ratios of organisms present at that time. Often these organisms can be pathogenic to plants and cause disease. As soil warms up and becomes moist (as distinct from saturated) organisms that have been suppressed by cold, wet conditions thrive again and, in turn, plants growing in that soil also thrive.

Soil chemistry is also altered by seasonal conditions, with soil pH, for example, changing as soil moisture and temperature changes. Periods of high rainfall can leach soluble nutrients out of the upper layers of the soil, often to below the depth where plants can access them. This is especially so in light sandy soils, but is not the case in heavier soils such as clays.

Periods of high rainfall can alter the physical nature of soils by causing compaction layers in some soils and various forms of erosion such as sheet, rill, gully and tunnel erosion.

On the other hand, long periods of hot, dry conditions can make soil prone to wind erosion, which occurs when the soil surface becomes denuded of plant cover so loose soil particles are simply blown away.

Tropical climates are especially harsh on soils, as periods of often intense rainfall events can cause severe erosion and soil nutrient leaching. Soils may also be subjected to extended periods of inundation. A large difference between tropical and cool temperate soils is that in the tropics when it is wet the temperature is normally high, which encourages periods of rapid plant growth. This in turn helps protect the soil from erosion and the plants are able to access nutrients before they are leached out of reach. Soil microbiology is extremely active during the tropical wet season and dead plant material on the soil surface will rot down to humus in an amazingly short time, thus the upper organic layers of the soil are constantly replenished. Tropical jungle soils are in a sustainable balanced situation and will thrive indefinitely without interference.

Where jungle growth has been cleared for agricultural use the soil is almost immediately subject to degradation and must be carefully managed to prevent severe damage occurring from erosion, nutrient leaching and structural decline.

Types of soils

Soils vary due to the parent materials they are made from and where they are located in the landscape. Broad descriptive terms include: hill soils and river flats, light or heavy soils, acid or alkaline soils, for example. Some more specific descriptions used in the past, such as sandy, sandy loam, loam, silty loam, clay loam and clay, have been based on particle size. These terms refer to the topsoil only with subsoils usually referred to as light, medium or heavy clays, further divided into more descriptive terms such as light sandy clays, medium silty clays and so on. This system is based on the relative proportions of the soils' components, with sand, silt and clay as shown in Figure 1.

More recently, soil terminology has become much more specific with the introduction of the 'Australian Soil Classification System' as shown in Figure 2. This system considers the topsoil, subsoil, soil chemistry and location of the soil for the classification. It is a scientifically precise and descriptive system and once learned allows accurate comparison of soils throughout Australia, unlike the earlier system. One advantage of this is that if it is found that a particular soil, say a 'Rudosol', needed specific management in one area it is likely that the same problem could exist in other parts of Australia as well. This could lead to better understanding of soils and their management generally.

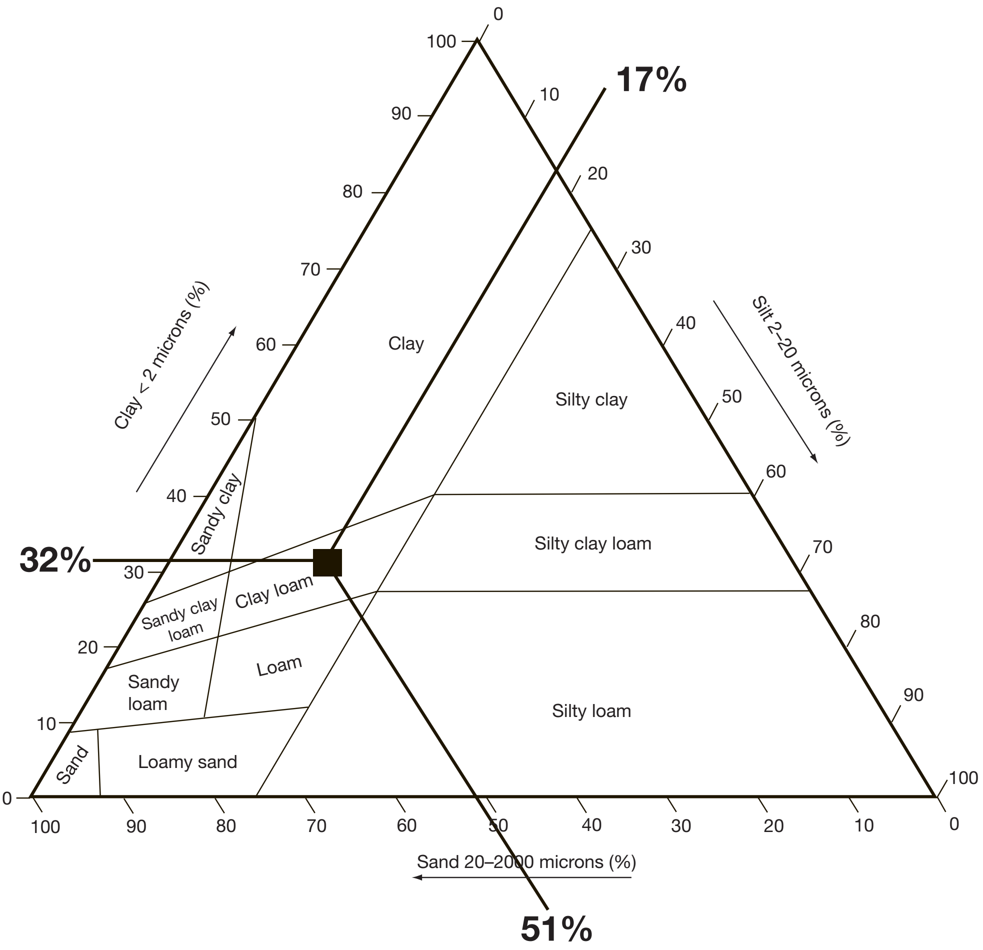


Figure 1 The soil textural triangle and example of composition of a clay loam. (Price 2006)

Soil fertility

What constitutes a fertile soil depends on a number of factors including soil structure, soil chemistry and soil microbiology.

Plants require water, warmth, sunlight, air (oxygen) and nutrients in the right balance to grow and thrive. All these components need to be available in the right proportions for each type of plant being grown and for the stage of growth of the plant. For example, some plants, such as azaleas, require acid soils, while some, such as beans, prefer alkaline soils. Subterranean clovers generally cope with moderately acid soils and medics require almost neutral to alkaline soils to thrive.

There are specific light or temperature requirements to enable some seeds to germinate. This is a mechanism to ensure survival in harsh natural conditions.

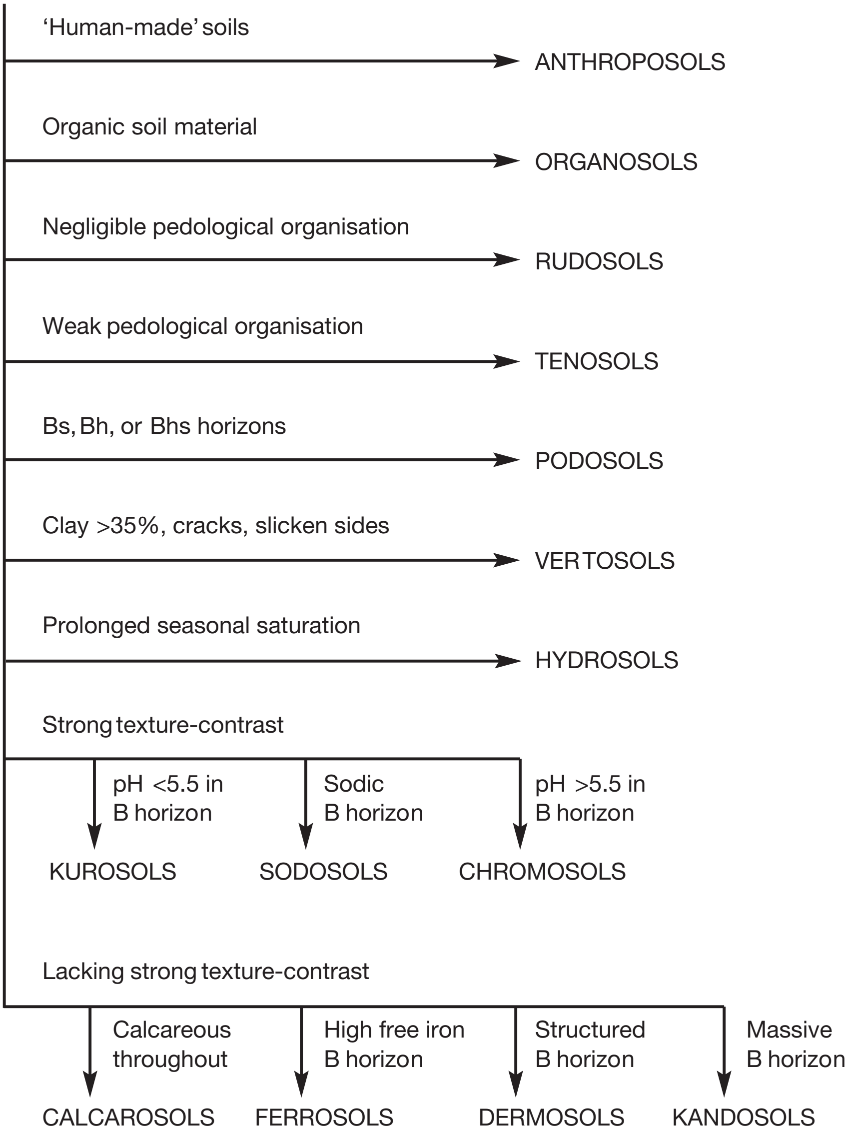


Figure 2 A classification system for Australian soils. (Isbell 2002)

Almost all farmed plants require oxygen in the root zone and oxygen availability depends on the soil structure having sufficient pore spaces to allow air to infuse into the soil profile. Often roots will only go as deep as the oxygen supply and this not only depends on soil structure but can also be reduced by high water tables or waterlogging.

Soil nutrient levels are critical to plant growth and a deficiency or excess of a particular nutrient can drastically reduce growth rates or even kill plants. Nutrient availability depends on the origin of the soil and the soil pH. For example, soils derived from granite are naturally acidic, while soils derived from some basalts or limestone are naturally alkaline. Farming practice may also change soil pH levels over time due to nutrient export and fertiliser effects.

To summarise these comments, a fertile soil is one that provides the physical conditions and all the chemical needs of plants and microflora. Typically, it will be a well-structured soil with a high proportion of air spaces between soil particles. It will have sufficient levels of all the nutrients required to support plant and microbiological growth, adequate water supplies with good infiltration rates and good drainage.

It will be of medium texture, sufficient to hold nutrients without excessive leaching, but loose enough to allow plants to extract the nutrients easily, that is, it will have a high *cation exchange capacity*. The soil will also have structural integrity. It will not easily be broken down by mechanical influences such as pressure from livestock or reasonable levels of cultivation.

Obviously, different soils have degrees of soil fertility, ranging from highly fertile to infertile. There are a number of ways of expressing soil fertility, one of which is shown in Table 1.

Table 1 Soil fertility classes

Class 1	Excellent productivity for all agriculture and horticulture
Class 2	Very good for most agriculture and horticulture
Class 3	Good for a range of agriculture and some horticulture
Class 4	Fair for a limited range of agriculture
Class 5	Low yields, pastures and some crops only
Class 6	Unsuitable for general agriculture

2

Soil pH

Background

Soils are made up of varying quantities of sand, silt, clay and organic matter, both living and dead. A soil with good structure allows water to move down the soil profile, and even when a soil appears dry there is still some water in it. This water contains dissolved chemicals that can cause the soil to be acid or alkaline. The acidity or alkalinity level can change over time and will affect how well plants will thrive in that soil.

What is the pH scale?

The unit of a scale used to measure the level of acidity or alkalinity of chemicals is called pH. The unit pH relates to the number of hydrogen ions in a solution, and ranges from pH 0 (most acid) to pH 14 (most alkaline), with pH 7 being neutral.

The pH range for most soils is between pH(w) 4 to pH(w) 10 (Figure 3).

Testing soil pH

There are two main laboratory techniques for measuring soil pH: one measures the pH of soil mixed with water, and the other measures the pH of the soil in a calcium chloride ($CaCl_2$) solution. It is important to bear in mind that laboratories may use either or both of these testing methods, and that the figures obtained will differ between methods.

pH range	
5.5 or lower	Highly acid
5.6–6.0	Moderately acid
6.1–6.9	Mildly acid
7.0	Neutral
7.1–7.7	Mildly alkaline
7.8–8.3	Moderately alkaline
8.4 or higher	Highly alkaline

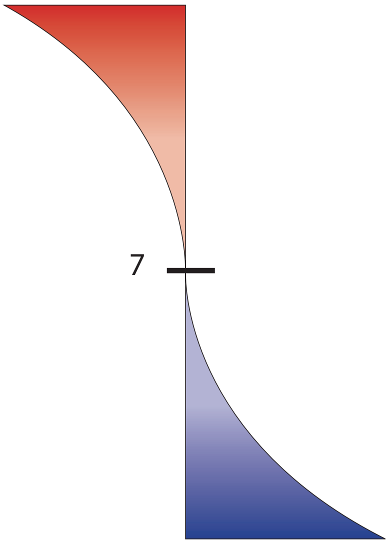


Figure 3 The pH scale as related to soil. (*Soil Sense* C-03)

(1) pH in water (pHw)

A measured quantity of dried and sieved soil is shaken for one hour with a measured quantity of pure water (usually one part soil to five parts water), mixed well and then tested. The results using this method more closely reflect current soil conditions than the calcium chloride method and therefore the actual pH to which plant roots are exposed at that point in time.

(2) pH in calcium chloride (pH$CaCl_2$)

A measured quantity of soil is mixed with a measured quantity of a standard calcium chloride solution, shaken for one hour, and tested. The readings given by this method are usually lower than the water method by 0.5–1.0 pH units, but more reliably predict the likely response to lime treatment.

In low salinity soils the pH in water will measure 0.6–1.2 pH units more than the pH in calcium chloride. In high salinity soils, the readings will be much closer, typically a 0.1–0.5 pH unit difference. The calcium chloride method shows less seasonal variability than the water method and is a useful diagnostic measurement as soils can be sampled at any time during the year and more confidently compared with previous results.

What do the results mean?

There are a number of things to consider when interpreting soil test figures for pH:

- Which crops or pastures will grow best in a soil of a particular level of acidity or alkalinity?
- What is the availability or non availability of soil nutrients due to the soil pH level?
- What are the trends in soil pH levels over time?

Plant responses

Most plants prefer a pH(w) range between 6.0 and 7.5, but will grow outside this range (although yield may be affected). How far outside this range plants will grow varies between the species (Figure 4).

Soil biological activity is also affected by soil pH. This becomes important approaching the extremes of acidity or alkalinity, when, for example, various species of earthworms and nitrifying bacteria disappear. Rhizobia strains vary in their sensitivity to soil pH, and have preferred ranges in which they are effective (Figure 5). Most soil organisms function best between pH 6.0–7.0.

Availability

Soil pH will influence both the availability of soil nutrients to plants and how the nutrients react with each other. At a low pH, many elements become less available to plants (see Figure 4), while others, such as iron, aluminium and manganese become toxic to plants and, in addition, aluminium, iron and phosphorus combine to form insoluble compounds. In contrast, at high pH levels calcium ties up phosphorus, making it unavailable to plants, and molybdenum becomes toxic in some soils. Boron may also be toxic at high pH levels in some soils and deficient in acid soils (Figure 6).

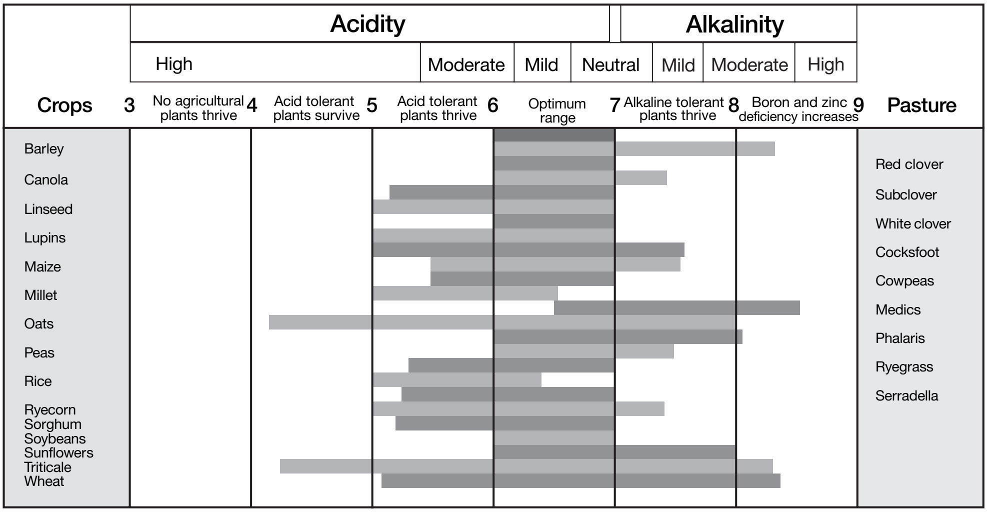


Figure 4 Preferred pH(w) ranges for plants. (*Soil Sense* C-03)

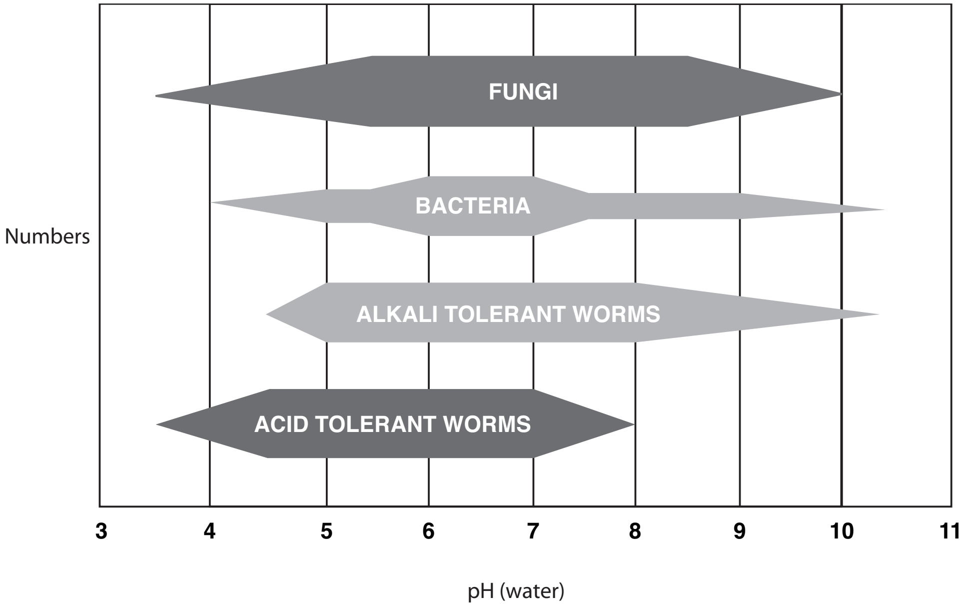


Figure 5 Influence of pH on soil organisms. (*Soil Sense* C-03)

Response to pH test results

Results that indicate very low or very high pH levels show the soil has major problems for supporting normal plant growth.

(1) Low pH (acid soils)

Some soils are naturally acid, while others have become acid over time through management practices such as product removal, nitrate leaching and consistent use of large amounts of nitrogen rich fertilisers, with the worst case being when the subsoil becomes acid as well as the topsoil. Acidity in the topsoil can be corrected by using one of a number of forms of lime and the economics of using lime should be considered in terms of productivity and sustainability. The trend over a number of years is the important issue, and soils that are becoming progressively more acid indicate a change in management is required. A soil with a pH(w) of 5.5 or lower is in need of special management to be sustainably productive, for example, by using the short-term measure of growing acid-tolerant species and applying lime for longer term benefits.

(2) Moderately to slightly acid soils

The important consideration is whether the trend in acidity over time is stable or increasing. If it is increasing, occasional liming and/or a change in management practices is needed.

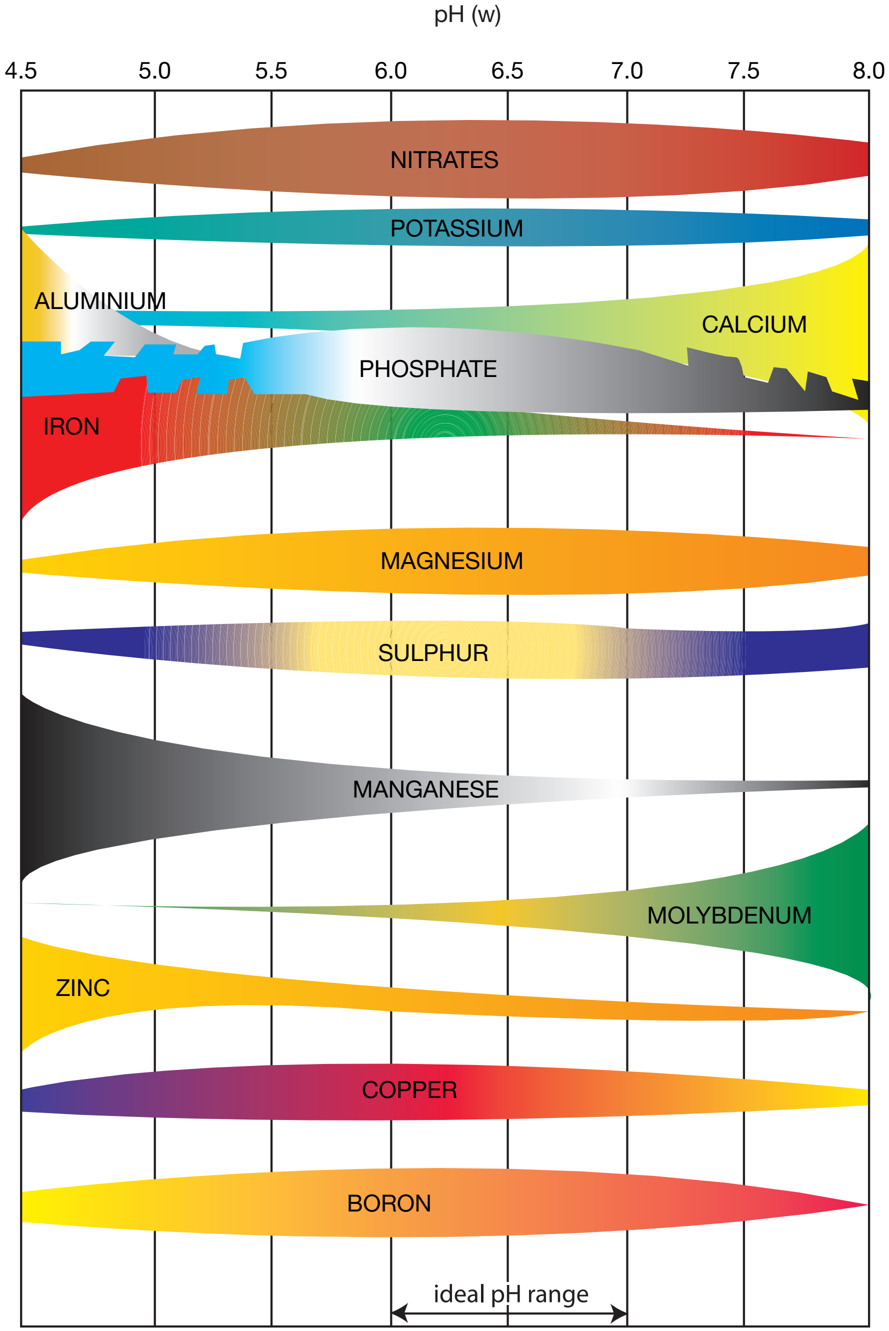


Figure 6 Effect of pH on availability of plant elements. (*Soil Sense* C-03)

(3) High pH (alkaline) soils

These soils are usually derived from limestone or basalt and are found, for example, in the Mallee regions of Victoria, South Australia and New South Wales, and the Darling Downs in Queensland. Alkalinity can be reduced by adding acidifying fertilisers such as ammonium sulphate, sulphur, or by consistent use of DAP (di-ammonium phosphate); however, very few soils show an economic response to these treatments. This is due to excessive amounts of free limestone in the soil that simply react with the applied fertiliser, leaving the soil pH much the same as it was before treatment. Soils with a pH(w) of 8.0 or above will require special management, and the range of suitable crops will be limited. Consistent use of legume crops may help reduce pH levels over time. It is also essential to attend to any nutrient deficiencies in these soils (see Figure 4).

What happens if nothing is done?

Again, the most important aspect of soil pH is the trend over time. Soils becoming progressively more acid will eventually end up quite infertile over time if nothing is done to reverse the trend. Acidic soils have lower potential production and therefore adversely affect farm income. The option of doing nothing to treat slightly acidic soils may be acceptable if management does not lead to increasing acidity over time. Farm income will be significantly lower than that which could potentially be achieved if pH was not a limiting factor. The risk with this management option is that acidity will increase with time.

3

Nutrient balance in the soil

Background

Soil studies have confirmed that for healthy soils, plants and animals, the various plant nutrients need to be present in balanced proportions. The amount of each nutrient can be determined by soil tests, and it is important that subsoils are tested as well as topsoils.

Plant nutrition

Plants need to be able to access all their food nutrients from the soil in sufficient amounts to grow to their full potential. These nutrients must also be in the correct balance (or ratios) for healthy plant growth. Incorrect balances will cause the plants to become prone to disease or insect attack and they will not grow to full potential.

Soil pH

Soil pH should ideally be around pH 6.5 (water) or pH 6.0 in calcium chloride for best biological and chemical activity. At this pH, toxicities and deficiencies are minimised due to chemical actions. The potential for the best macro- and microbiological growth also occurs at this pH, but this is also dependent on temperature and moisture. The soil chemical reactions that are dependent on acidity still continue at this pH level, helping to make the nutrients available to plants.

Animal nutrition

Animals grazing a diverse range of productive plants grown on healthy soils will have a better chance to be healthy and grow to their genetic potential.

> *A healthy soil produces healthy plants that produce healthy animals.*

Nutrient ratios

All plant nutrients are important for different reasons, some of which alter the structure of the soil as well as providing nutrition for plants and soil microbiology.

The cations

This group of soil nutrients includes the elements:

Calcium (Ca)
Magnesium (Mg)
Potassium (K)
Sodium (Na)
Hydrogen (H)
Manganese (Mn)
Aluminium (Al). (Aluminium is not really a plant ‘nutrient’, but it is a cation.)

A soil analysis will usually show the ‘cation exchange capacity’ (CEC) of a soil, that is, the amount of calcium, magnesium, potassium, sodium, hydrogen, manganese and aluminium available. It has been found that the relative ratios of soil cations influence how well plants grow in the soil.

Calcium (Ca)

Calcium (that is found in limestone) helps counteract soil acidity and makes the soil friable. It is required in quite high amounts by some plants such as lucerne. Calcium should be between 65% and 70% of the CEC.

Magnesium (Mg)

Magnesium is required in much lower quantities than calcium. In excess it causes clay subsoils to become very dense and blocky, thus reducing root and water movement downwards. Magnesium can also be used to raise pH levels in soil. Magnesium should be between 15% and 20% of the CEC.

Potassium (K)

Potassium is only required in relatively small amounts. Generally in soil it ‘cycles’ between plant available and plant unavailable forms as conditions within the soil change. Deficiencies are very important in plant physiology and show up as slow spindly growth or bright yellow leaves, lack of cold tolerance and ineffective use of water. Potassium should be about 5% of the CEC.

Sodium (Na)

Sodium is required only in small amounts by plants, and an excess in the soil can have severe effects on plants and the soil. An excess of sodium in the soil will cause clays to have poor structure, becoming dispersive and settling into hard layers, which resist root penetration and water movement. Soils with too much sodium compared to calcium are said to be ‘sodic’ (this is different from saline). Exchangeable sodium should be less than 5% of the sum of cations, that is, calcium + potassium + magnesium + sodium + hydrogen added together (and manganese and aluminium in acid soils).

$$\frac{\text{Exchangeable Na}}{\text{Exchangeable Ca + K + Mg + Na + H}} \times \frac{100}{1} = <5$$

A guide to the level of soil sodicity is:

0–5	low sodicity
6–15	medium sodicity
>15	highly sodic

Carbon/nitrogen ratio

This is a characteristic of the organic part of the soil where most of the biological activity occurs. It is a result of the formation of humus and organic matter, the decomposition of dead plants and animals, and the amount of soil organisms present, such as bacteria, fungi, earthworms, insects and other soil organisms. This is all about ‘living soil’ and for many years it has been known that the amount of production that can come from above the soil is directly dependent on what is growing under the soil surface. A good ratio of organic carbon to soil nitrogen is 10:1–12:1.

Macro- and micronutrients

The macronutrients – nitrogen, phosphorus, potassium, calcium and magnesium – are all essential for plant growth, and are required in larger amounts than other plant nutrients. Needs vary between plant species and growing conditions, and should be worked out on a crop by crop basis in conjunction with soil testing.

The micro, or trace, nutrients, are all required in very small amounts, but are essential for healthy plant growth. The availability of these nutrients is often dependent on soil pH, and in strongly acid or alkaline conditions they may be either unavailable to plants or available at toxic levels. (Refer to Chapter 9.)

Keeping soil at near neutral or slightly acid pH overcomes many problems with trace elements, but if deficiency signs occur in crops, or if a known deficiency is present, the required trace element should be added.

Antagonism between nutrients

When talking of nutrient deficiencies or excesses we are talking about fine tuning the balance of each plant food in the soil. Too much of a nutrient may be even worse than too little for the reason that it may be hard to remove excesses (e.g. sodium or manganese). Some of the plant nutrients in excess can cause other deficiencies in plants by interfering with the uptake of a nutrient that would normally be in adequate supply. Overdosing with one plant nutrient may change the availability of others. Table 2 shows some examples.

> *Just as it is possible to have too little of a nutrient in the soil, it is also possible to have too much.*

Table 2 Some soil nutrient interrelationships in plants

Nutrient in excess	Induced deficiency
Nitrogen	Potassium
Magnesium	Potassium, nitrogen, phosphorus. Calcium shows as magnesium deficiency
Potassium	Magnesium, sodium, calcium
Sodium	Calcium, potassium
Calcium	Phosphorus, magnesium, trace elements
Boron	Potassium, magnesium
Chlorine	Potassium

As well as soil nutrients affecting plant health, nutrients supplied to animals from plants grown on the soil also affect animal health, as shown in Figures 7 and 8. If an arrow points from one nutrient to another, it means a deficiency in the nutrient the arrow is pointing to may be caused by excess of the first nutrient. A nutrient in excess can affect more than one other nutrient.

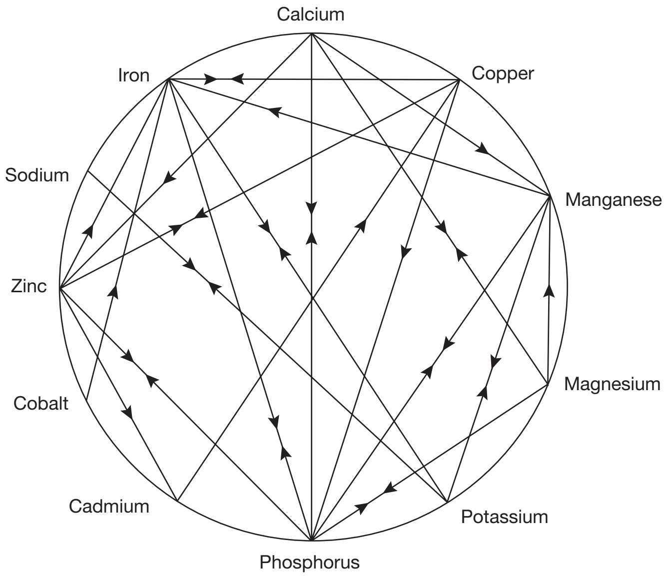


Figure 7 Mineral interrelationships in animals. (*Soil Sense* C-01)

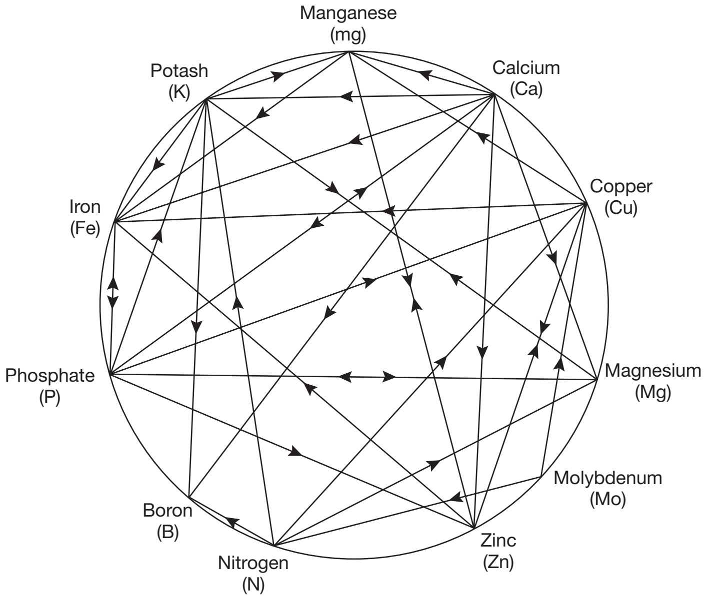


Figure 8 Mineral interrelationships in plants.

Determining the nutrient balance of the soil

The amount of nutrients present in the soil is best determined by taking soil samples and having them tested in a laboratory. Soil testing is a very useful tool to help understand what the current nutrient status of the soil is, and to decide on a fertiliser program. The cost of soil testing is nearly always returned many times over by better crops or pastures. An alternative to soil testing is plant tissue analysis, which will indicate nutrient availability to the plant at the time the sample was taken, but will not indicate total nutrient levels in the soil or balances between nutrients.

Reasons for soil testing

Advantages of soil testing are:

- to improve the balance of exchangeable cations for optimum soil structure and friability
- results show the relative levels of nutrients in the soil
- results show pH, which can influence nutrient availability
- enables calculations of nutrient ratios
- enables fertiliser programs to be targeted to soil and crop needs
- saves money on applying fertilisers – only necessary ones need to be applied
- normally means better crop responses from applied fertilisers.

Alternatives to soil testing

Plants growing in nutritionally unbalanced soils will show it in their growth habits, for example, leaves may be yellow or have dry edges, roots may be stunted or fruit may be deformed. Knowing what these signs mean can give an indication of what nutrient is missing or is in excess, but a great deal of experience is needed to use this method successfully, as it is difficult to decide between nutrient deficiencies or toxicities, or whether the symptom is caused by antagonism between nutrients.

Action following soil testing

To fully benefit from soil testing, the following steps should be taken:

(1) Determine pH

Ideally the pH should be 6.5 in water or 6.0 in calcium chloride. This allows soil acid chemical reactions to occur, but will not cause toxicity problems. A pH as low as 5.0 in calcium chloride may be acceptable if well managed and manganese is not in toxic amounts. Aim to have a slightly acidic pH so that soil conditions are ideal for soil micro- and macro-organisms, which in turn improve plant growth by supplying nutrients from the decomposition of organic matter.

Note. Soil pH is also a consequence of the cation balance, and this should be adjusted if necessary to change the physical structure of the soil as well as its chemical composition.

(2) Adjust pH levels
The pH can be adjusted by liming if pH is low, or adding acidifying agents if high, within economic limits. Rather than just considering pH in isolation, it should also be considered with cation balance and organic carbon. Balancing cations may well change soil pH, at the same time changing the need for other action.

(3) Calculate nutrient ratios
Nutrient ratios should be calculated for calcium, magnesium, potassium, sodium and the carbon/nitrogen ratio. Again, these ratios are aimed at obtaining ideal soil conditions for soil macro- and micro-organisms and therefore for nutrient cycling and for plant growth.

(4) Decide
Decide on where deficiencies or toxicities are.

(5) Calculate
Calculate how much fertiliser is needed to correct deficiencies and adjust ratios based on the soil tests.

(6) Apply
Apply appropriate fertiliser with respect to economic limits.

This is not an easy job as it requires a good understanding of the effects of each fertiliser considered, and requires time spent doing calculations. The advantages of doing this job well will provide many benefits to the soil, and more particularly, to the bank account at the end of the growing season.

Note. As soil is a dynamic living system, ideal ratios of nutrients will vary over time and depend on the plants utilising the soil. There is no hard and fast rule that can be applied all the time to a soil without taking seasonal variations into account.

4

Carbon in the soil

Background

Carbon is a chemical element and is written in chemical form as C. Carbon is not usually found on its own in soil unless as charcoal from burnt animal or vegetable material, but as carbon-based compounds including carbohydrates and proteins. These compounds are the building blocks for all forms of life.

Unlike the inorganic chemicals in soil such as calcium, phosphorus, potassium and so on, carbon 'cycles' in fertile soils depending on the biological actions of living organisms above, on, and in the soil profile.

Carbon is present in greatest concentration in the upper organic layer, on or close to the surface of the soil. It is present in decaying plant and animal matter, in products like humus, and in the gaseous forms of carbon dioxide and sometimes as methane in soil pore spaces.

Carbon is a vital component of all living things, including plants, animals, fungi and bacteria, all of which play their part in creating and maintaining a fertile, healthy *living soil*.

The carbon cycle

Green plants convert atmospheric carbon dioxide into carbohydrates by the process of photosynthesis. These carbohydrates in the form of sugars and starches are formed in the green leaves of plants, and are distributed to all parts of the plant above and below ground level by sap flow. As the plants mature and die, these carbon compounds are used as food by animals and other soil biota. This carbon is subsequently made available in the soil as humus, compost, and chemicals such as humates, fulvates and carbonic acid. These chemicals in turn can react with inorganic chemicals in the soil, making them available to plants for uptake through their roots. As this carbon ends up in the food web, it is converted back into gaseous carbon (as carbon dioxide and methane) and returned to the atmosphere to begin the cycle again (Figure 9).

Soil tests for carbon

Estimates of organic carbon (OC) in the soil are used to express the amount of organic matter present.

Levels are highest in the surface layers, and in Australian soil may vary from almost zero to 15% or above. Due to the harsh Australian climate, stable organic carbon levels in the soil are usually quite low at around 2%, with reasonable levels at around 4%. Soil carbon levels can be increased reasonably easily, but will not remain at elevated levels without regular inputs, and in time will revert back to the sustainable base level.

Soil test reports usually show organic carbon as a percentage of total soil mass.

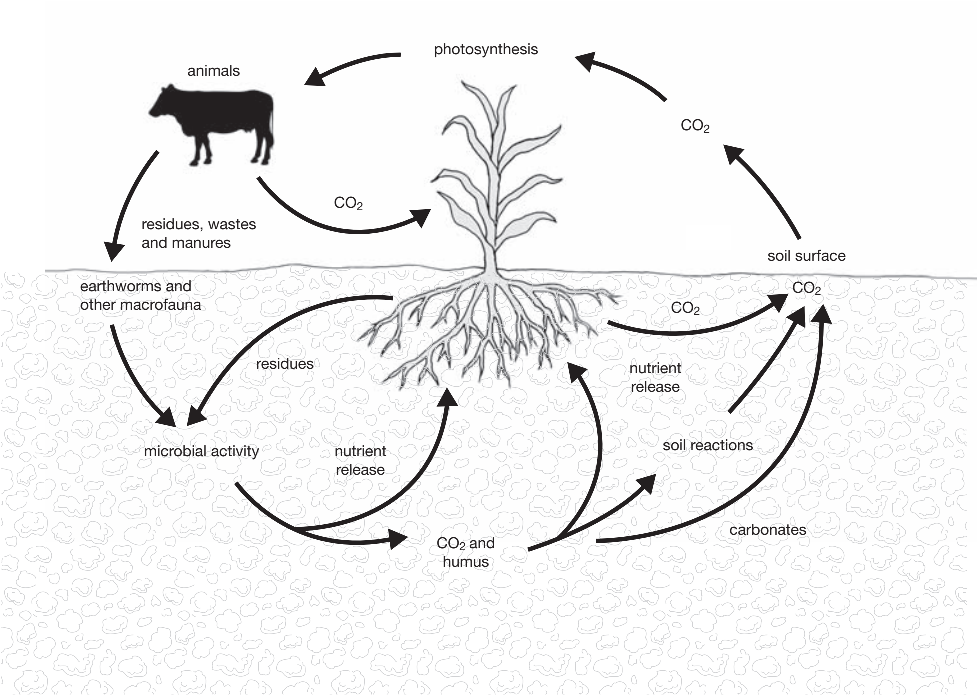


Figure 9 The carbon cycle.

Interpretation of the soil tests

The soil test for carbon will give an indication of the biological activity in the soil at a point in time, and is only indirectly related to the needs of plants growing in that soil. However, this does not mean it is not important and, in fact, it is probably the most important figure in the whole soil report.

Soil carbon levels relate directly to the biological health of the soil, which in turn relates directly to how well plants can grow in the soil. Soil pore spaces can be considered as 'houses' for soil microbiology, which in turn is the most vital part of the living web of life on the planet. Soil microbiology is part of a whole series of complex, integrated steps, from small simple life forms, to larger more complicated forms, and ultimately to the largest, most demanding life forms on the planet. Without these microscopic life forms in the soil, life as we know it on planet Earth would be impossible.

Managing soil carbon

As already stated, soil carbon levels are directly related to soil microbiology, so to modify soil carbon levels we need to modify soil microbiology and carbon is best added to soil in conjunction with living plants.

> *Soil can be considered as a living entity in its own right.*

Basically, soil microbiology has the same requirements as plants: food, water, warmth, air (oxygen) and shelter. For soil microbiology, food can be supplied in the form of decaying plant and animal matter and exudates from living plants, plus essential nutrient elements. These nutrient elements may be supplied in decaying plant and animal matter, in the inorganic components of the soil or added to address any deficiencies present.

Water supplies need to be consistent, ideally not too dry and not too wet. Soil temperature is important, and the microbiology is most comfortable at temperatures we would find comfortable. As the microbiology is made up of living organisms, a consistent oxygen supply is essential. This is normally supplied by maintaining good open structure in the soil. Shelter for soil microbiology is also provided by the pore spaces in the soil, and to a lesser extent by plant cover on top of the soil. Plant cover has a modifying effect on the soil, keeping temperature and moisture levels more even, which encourages microbial growth.

Increasing soil carbon levels

If soil carbon levels are lower than desirable, they may be increased in a number of ways:

- Manage the soil to maintain or increase soil crumb structure and soil pore spaces.
- Add carbon as stubble mulching, green manuring, compost, humates, fulvates or molasses.
- Maintain dense plant cover on the soil. Green plants add carbon.
- When conditions are suitable, add suitable commercially available microbiological products.
- Encourage larger forms of life such as earthworms.
- Do not use chemicals that will harm the microbiology already present or about to be introduced.
- Keep soil pH at around neutral, and balance soil cations.
- Keep stock and machinery traffic on the soil to a minimum. Use rotational grazing techniques.
- Keep soil moist if possible.
- Encourage good plant root development by shallow to deep ripping when conditions are right.

5

Nitrogen in the soil

Background

Nitrogen is a chemical element and is written in the chemical form as N. Plants and animals require nitrogen to build proteins that are important in the quality and quantity of plant material produced, and in the health of animals feeding on healthy plants. In chemical terms, proteins are composed of carbohydrates plus nitrogen (and usually sulphur). Legume plants are able to fix atmospheric nitrogen in conjunction with colonies of rhizobia bacteria located in root nodules, and in time this nitrogen becomes plant available. Azotobacter algae are also able to fix atmospheric nitrogen that becomes plant available over time. Other sources of plant available nitrogen are decaying plant and animal matter, and nitrogen compounds produced by thunderstorms. Nitrogenous fertilisers may also be added to the soil or sprayed directly onto plants as foliar fertilisers. There is a large difference between various plants in their nitrogen requirements for optimum growth, and plant species present can be an indication of the nitrogen status of the soil.

Nitrogen in the soil

For plants to use nitrogen, it must be available to them in a soluble form, and this is usually as nitrate (NO_3), or as ammonium (NH_4). These forms of nitrogen can be produced in or near the soil by the action of soil macro- and micro-organisms as they break down (decay) organic matter, or can be supplied directly by adding fertilisers such as urea, various ammonium or nitrate salts such as ammonium nitrate, potassium nitrate, calcium ammonium nitrate or as anhydrous ammonia.

Plants need significant quantities of nitrogen for rapid growth, especially in spring as the weather warms up, or if soil is showing signs of waterlogging. It should be mentioned that nitrogen is not used alone by plants, but with a whole range of other plant nutrients in the correct balance. These are made available over time, often as a result of complex chemical reactions, as larger molecules are broken down to simpler molecules that the plant can use.

Nitrogen is removed from the soil by harvesting crops and pastures, and by grazing animals. Dung and urine from animals does return significant quantities of nitrogen, but unless paddocks are managed well the returned nitrogen is unevenly spread, tending to concentrate in stock camps, under trees and near gateways.

Nitrogen is also removed by leaching through the soil profile, and may leach below the plant root zone, thus making it unavailable. This is especially true with light sandy soils in high rainfall areas, or irrigated pastures or crops, but is not such a problem in heavier clay soils in low rainfall areas or in dryland farming. Nitrogen may also be lost from the soil in gaseous form, returning to the atmosphere.

Nitrogen is an important component in the soil pH status, and unused ammonium nitrogen compounds when converted to the nitrate form can rapidly acidify soils, for example, if there is an imbalance between legumes (that add nitrogen) and grasses (that use nitrogen).

Nitrogen in plants

Nitrogen plays an essential role in the production of chlorophyll in plants, so adequate quantities are vital for healthy plant growth. It is also an integral part of plant protein, usually in conjunction with sulphur, and is found in other plant compounds such as amino acids. Chemically, proteins are built by adding nitrogen to carbohydrates such as sugars and starches that have been made in the plant by photosynthesis.

Legumes in conjunction with rhizobia bacteria are able to ‘capture’ nitrogen from the atmosphere and fix it in nodules attached to the plant roots. As these nodules break down, plant available nitrogen is released to the soil that can be used by other species of plants such as grasses, and can also be accessed directly by the nodule forming legume.

The increased production of chlorophyll in plants due to nitrogen leads to more photosynthesis and hence higher production of sugars and starches within the plant. This increases vegetative growth, and with plants in the grass family will lead to increased tillering and seed yield with higher seed protein levels.

If available nitrogen is at low levels, the plant will tend to use what nitrogen there is to produce vegetative growth at the expense of seed production. Nitrogen can, however, be translocated in the plant from senescing leaves to seed production as old leaves die and fall off, which will partly make up for the low nitrogen availability in the soil.

The form in which nitrogen is available to plants can influence plant growth. Organic nitrogen that is available over time (slow release) will provide nitrogen over the various growth phases of a plant's development. This can effectively increase plant yield as there are no stages of the growth of the plant that are limited by insufficient nitrogen at a point in time. If highly soluble chemical fertilisers are used, the nitrogen tends to be available for a relatively short time only, and is at risk of leaching if applied in excess to the plant's immediate needs.

Multiple applications of chemical-based fertilisers can achieve the same thing as slow release organic fertilisers, but may not be economically viable and also runs the risk of damaging existing soil microbiology.

The nitrogen cycle

Soil and plant nitrogen levels are dynamic, and vary over time according to the inputs and outputs from the natural environment and from changes brought about by farming practices. Figure 10 illustrates the basics of this dynamic cycle.

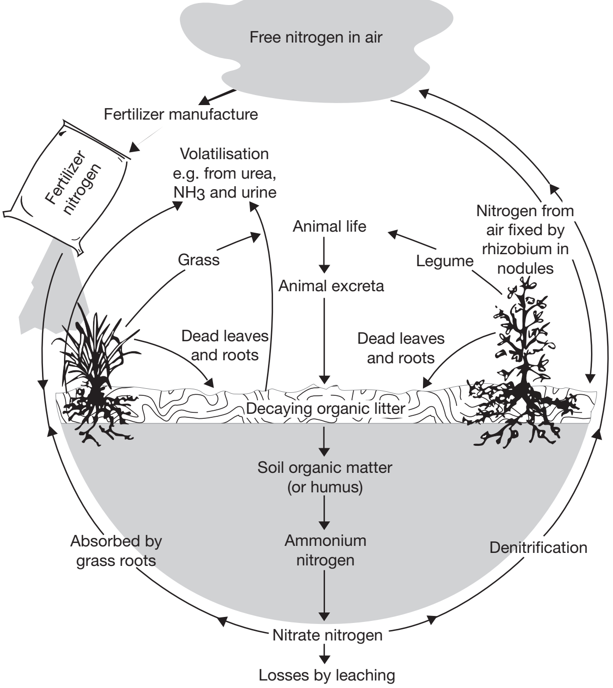


Figure 10 The nitrogen cycle. (Price 2006)

6

Phosphorus in the soil

Background

Phosphorus is a chemical element and is written using the symbol P. Plants require phosphorus for cell division and growth, especially in their early stages. As most Australian soils are low in plant available phosphorus (in the orthophosphate form), adding phosphatic fertilisers is necessary for good plant growth. Results of soil tests will give a guide to how much fertiliser is needed.

Alternatively, if high levels of fixed phosphorus are present, it may be converted to plant available forms by adding the appropriate VAM (vascular arbuscular mycorrhizae).

> *If phosphorus is the limiting factor to crop growth, the yield will be substantially lower than the maximum yield potential.*

Phosphorus in the soil

When a phosphatic fertiliser is applied to the soil a number of complicated chemical reactions start to occur. As the fertiliser dissolves it releases phosphatic salts, some of which react with the soil ions, iron (Fe), aluminium (Al) and calcium (Ca), forming insoluble compounds that makes the phosphorus unavailable to plants. This problem is much worse in acidic soils (where iron and aluminium are the problem), or highly alkaline soils (where calcium is the problem), than in soils close to neutral pH. These reactions can occur in a short space of time, maybe even in hours.

Result:

- Part of the applied phosphorus is immediately plant available.
- Part forms a bank of less available phosphorus (slow release).
- Part is ‘fixed’ and is mostly unavailable to crops and pastures.

Part of this ‘unavailable’ phosphorus may, however, be accessed by ‘soil micro-organisms’, particularly mycorrhizae that can then pass it on to crop plants. Phosphorus uptake by plants is also reduced in compacted soil due to restricted root growth.

Young organic matter decaying in soil releases plant available phosphorus, although phosphorus combined in older forms of organic matter is released slowly over time. On a sustainable farm, there is a continual cycle of use and reuse of phosphorus, although the phosphorus removed from the farm in plant material through cropping, grazing or fodder conservation must be replaced by added fertiliser phosphorus to maintain the balance. The amount of plant available phosphorus in soil may decrease over time due to pH effects on soil micro-organisms.

Soil tests

Different states of Australia have different methods of testing for phosphorus. In Victoria, the normal test for plant available phosphorus is called the Olsen P test (sample results are shown in Table 3). Results are given in mg/kg (milligrams of phosphorus per kilogram of soil). In New South Wales and South Australia the normal test is the Colwell P test. It is similar to the Olsen P test, but values are higher and are also expressed in mg/kg (milligrams per kilogram). Another method of testing that is frequently used in New South Wales for available phosphorus is the Bray Test.

What do the results mean?

Soil tests give a guide to the likely responses by crops or pastures to the application of phosphorus fertiliser. The plant needs vary depending on the type of soil, with the optimum phosphorus level lowest on sands, followed by loams, clays and peats, with calcareous sands having the highest requirement. The type of enterprise will also affect the amount of fertiliser required (Table 3).

Note. Native tree and shrub seedlings can only tolerate low levels of phosphorus, and when grown commercially, should only be fertilised with low levels of P.

Table 3 Olsen P levels in soils (in milligrams per kilogram)

(Source: *Soil Sense* C-05)

Olsen P levels	Dryland pastures	Irrigated pastures	Horticultural
low	<8	<15	<20
marginal	8–12	15–20	20–30
moderate	13–18	21–30	31–60
high	>18	>30	>60

Note 1. Due to the differing buffering capacity of soils, this table is a guide only.
Note 2. These figures are based on sandy soils. Loams and clays fix more phosphorus than sands but as accurate predictive methods are only available in New South Wales at present, regular soil testing is recommended on soils other than sands.
Note 3. The level of management also needs to be considered; for example, if you are aiming at 10 dse/ha or 25 dse/ha. The nutrient removal from the paddock also needs to be considered when deciding on the amount of fertiliser to use.

Tissue tests

Tissue tests measure the level of phosphorus in the plant itself, and are a reasonably accurate method of establishing the phosphorus needs of growing plants at the time the tissue was collected. If it is found that the plants need more phosphorus after tissue testing, it would be best applied as a foliar fertiliser.

How much fertiliser is needed?

The range of phosphatic fertilisers available varies in the amounts of phosphorus they contain (Table 4).

Table 4 Fertilisers containing phosphorus (1997)

N, nitrogen; P, phosphorus; K, potassium; S, sulphur; Ca, calcium. (Source: *Soil Sense* C-05)

Name of fertiliser (by company)	Nutrient analysis (%). Applied at 100 kg/ha provides _ kg of nutrient.					kg of nutrient supplied per tonne of product				
	N	P	K	S	Ca	N	P	K	S	Ca
Pivot										
Superphosphate		8.8		11.0			88		110	
Prolong 15		9.5		15.0			95		150	
Super Sulphur 20%		8.1		19.8			81		198	
Super Sulphur 35%		7.0		35.0			70		350	
Gyp Phos.		5.3		11.8			53		118	

Table 4 (continued)

Name of fertiliser (by company)	Nutrient analysis (%). Applied at 100 kg/ha provides _ kg of nutrient.					kg of nutrient supplied per tonne of product				
	N	P	K	S	Ca	N	P	K	S	Ca
Natura Phos.		13.4					134			
Gold Phos. 10		18.0		10.0			180		100	
Gyp Phos. 20		16.0		20.0			160		200	
Highfert										
Pasture Slow Release		12		16			120		160	
Pasture Slow Release		14		17			140		170	
D. A. P. S.	16	18		12		160	180		120	
Legume Special	6	16		10		60	160		100	
Highfert 0–20–0		20					200			
Superphosphate		9		11			90		110	
Incitec										
Super		8.8		11.0	20.0		88		110	200
Pasture Plus		15.1		15.2	13.9		151		152	139
Pasture P		17.3		9.5	14.3		173		95	143
Pasture Starter	6.5	13.6		8.6	9.8	6.5	136		86	98
Longlife		11.9		12.7	18.2		119		127	182
R. P. R.		12.4		1.4	30.4		124		14	304
R. P. R. Supreme		8.5		10.2	20.9		85		102	209
Pasture 13		6.5	12.2	8.1	14.7		65	122	81	147
Pasture 16		5.8	16.3	7.2	13.1		58	163	72	131
Pasture 25		4.3	24.5	5.4	9.8		43	245	54	98
S. F. 25		7.0		26.0	16.3		70		260	163
S. F. 45		5.6		42.0	12.7		56		420	127
Greentop	17.5	4.9		18.6		175	45		186	
After Graze	21.8	3.3	7.3	1.8	3.0	218	33	73	18	30
Nitro Graze	23.8	3.9	12.7	4.2		238	39	127	42	
Haymaker	11.9	4.6	23.1	4.6		119	46	231	46	
Legume Starter	5.0	15.3		6.9	11.0	50	153		69	110
Sulphos.		13.0		7.0	17.7		130		70	177
Starter Fos.	10.0	21.9		2.3		100	219		23	
D. A. P.	18.0	20.0		2.0		180	200		20	
Trifos		20.7		1.3	15.0		207		13	150

Worked example

Question: How much plain superphosphate (8.8% P) do I need to raise the Olsen P level of a dryland pasture on a sandy soil from a low 8 mg/kg to a moderate level of 18 mg/kg.

From Table 3: a moderate Olsen P level is 18 mg/kg. The current low Olsen P level is 8 mg/kg. So, the phosphorus required is 18 – 8 = 10 mg/kg.

From Table 4: 100 kg/ha of plain superphosphate adds 8.8 kilograms of phosphorus per hectare.

From Table 5: for a soil with a bulk density of 1.2 grams/cubic centimetre, it will require 1.8 kg/ha of phosphorus to raise Olsen P by one unit (1 mg/kg).

So, to raise the Olsen P by 10 units will require 1.8 × 10 = 18 kg/ha of phosphorus.

Therefore, if 18 kilograms of phosphorus per hectare is required and 8.8 kg per hectare is supplied by 100 kg of plain superphosphate: 18 × 100 ÷ 8.8 = 205 kilograms of plain superphosphate per hectare.

Note 1. Soil bulk density figures may be supplied in the soil tests.

Note 2. A rule of thumb figure is that 1 kg of phosphorus is required per DSE of production.

Table 5 Figures for calculating fertiliser requirements

	Soil bulk density (g/cm^3)	Figures for calculating fertiliser requirement
Good	1.2	1.8
Dense	1.4	2.1
Very dense	1.6	2.4

When should phosphorus be applied?

Plants respond best to phosphorus in the early stages of growth and when growing vigorously (Figure 11). As phosphorus becomes less available to plants over time, it is best applied when the plant can use it quickly, such as after the autumn break and at the spring flush (or both). With slow release fertilisers, such as rock phosphate, the time of application is less critical, but it would be best applied early in the season. Rock phosphate is only an option on acid soils unless it has been treated with appropriate biological additives. Soft rock phosphate and guano phosphatic fertilisers, however, are much more plant available, and do not adversely affect soil microbiology as chemically treated phosphate fertilisers do. Phosphorus applied in fertilisers will be partly available to future crops and pastures, but much of the applied phosphorus will become ‘fixed’, and will no longer be readily available to plants unless soil microbiology can unbind it and transfer it to the plants. This means that regular annual applications based on soil tests are better than a larger application every few years. For cropping, adequate levels of phosphorus should always be applied, as worthwhile net returns depend on high yields. If phosphorus is the limiting factor to crop growth, the yield will be substantially lower than achievable yields.

Note. Split applications of phosphorus are probably best done using foliar fertilisers, as phosphorus fertilisers top dressed onto the soil surface remain close to where they are placed, and do not easily move down into the root zone.

What happens if adequate phosphorus is not supplied?

If a paddock has a recent history of adequate phosphorus applications, it will probably have a reasonable level of residual phosphorus that will be partly available to a subsequent crop or pasture. This level can be enhanced by addition of appropriate soil microbiology.

If the paddock is only lightly grazed, there may well be enough phosphorus for one or two years, but if grazing pressure is high, production will be limited by lack of available P, and gross returns will be lower.

If adequate phosphorus is not available for growing crops, then potential yield will be lower than the maximum yield potential, and gross dollar returns will also be lower.

Phosphorus toxicity

Excess phosphorus in plants will cause yellowing of leaves and ill thrift in the plants. On rare occasions this is done deliberately, for example, when growing ‘Virginia leaf’ tobacco to obtain a golden dried leaf colour instead of the normal brown colour. In most farming enterprises, however, supplying too much phosphorus is practically and economically undesirable.

Excess phosphorus intake by animals (including humans) will lead to nutrient imbalance with calcium and magnesium, bone problems, sickness, breeding difficulties, and has been linked to cancer.

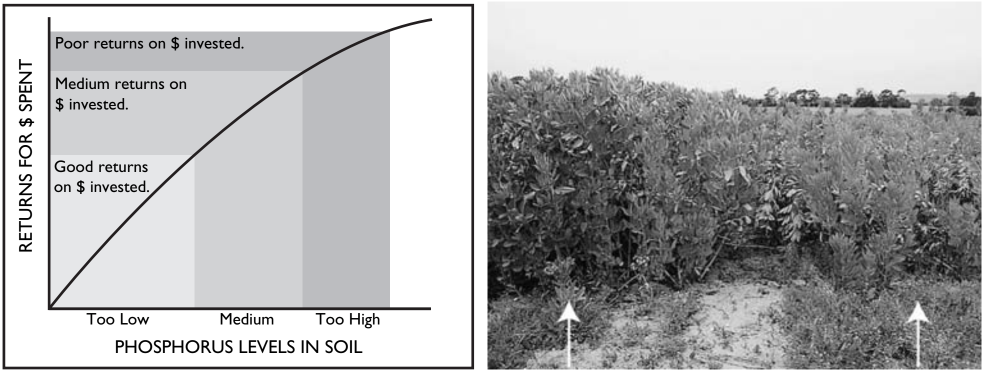


Figure 11 Plant response to applied phosphorus. In photograph, left arrow shows plants with phosphorus applied, while right arrow shows plants without phosphorus. (*Soil Sense* C-05)

7

Potassium in the soil

Background

Potassium is a chemical element and is written in chemical form as K. Plants require large amounts of potassium for a variety of metabolic processes, even though it is not part of the structure of the plant itself, but is present only in the sap.

Potassium is vital to plant metabolism and is involved in the following functions:

- enhances photosynthesis in the plant
- controls respiration rate in the plant
- is essential for protein synthesis
- is important in flowering and fruit formation
- provides energy for plant growth through breakdown of carbohydrates
- helps control ionic balances and translocation of metal ions
- helps plants cope with drought conditions and effects of disease
- improves cold tolerance in plants
- is involved in the activation of many plant enzyme systems.

Plants are able to take up more potassium than they actually need, so excessive amounts should not be applied.

Potassium deficiencies are common when dairying or haymaking on light soils. Responses to potassium fertilisers are particularly evident in clover and maize crops.

Potassium in the soil

Most soils contain large amounts of total potassium, but only a small proportion is readily available to the plant. As plants remove available potassium over time, previously unavailable potassium is modified by soil chemical reactions to become available to the plant. This is a slow process, however, and if plant products are removed from the paddock available potassium will have to be added to maintain short-term production levels.

> *The potassium to magnesium ratio in the soil is satisfactory if there is less potassium than magnesium.*

Soil tests for potassium

Soils are usually tested for plant available potassium by the Colwell or Skene methods. Results are quoted in micrograms per gram (µg/g) or milligrams per kilogram (µg/kg). Some soils such as the Riverine plains of northern Victoria show little response to potassium applications, even though soil tests indicate low available potassium levels, because the soil tests do not measure the 'unavailable' potassium in the soil (that may later become available).

Potassium deficiency can inhibit growth and plants may have small roots and leaves. Plants become spindly and need more water for respiration. Symptoms may show as scorching along leaf margins and small and shrivelled seed and fruit.

What do the soil test results mean?

The Colwell or Skene results give a guide to the likely responses by crops or pastures to an application of potassium fertiliser (Table 6). Plant needs vary with soil types, with the lowest need in sandy to sandy loam soils, and the highest need in clays, laterites and peats.

Table 6 Potassium levels in soil (micrograms per gram): Colwell or Skene methods of testing

K, potassium. (Source: *Soil Sense* C-06)

Skene K levels (0–10 cm µg/g)	**Pastures and crops**			**Horticultural**		
Level of K indicated	Sands	Loams	Clays	Sands	Loams	Clays
Low	<50	<80	<120	<80	<140	<150
Marginal	50–120	80–160	120–180	80–150	140–190	150–210
Moderate	120–200	160–250	180–300	150–230	190–280	210–330
High	>200	>250	>300	>230	>280	>330

How much fertiliser should be used?

Potassium is often applied as part of a complete fertiliser mixture containing nitrogen, phosphorus and potassium (N, P, K), but may be applied as potassium alone using potassium chloride or potassium sulphate, or in combination with nitrogen as potassium nitrate (Table 7, and Figure 12 on p. 105).

Table 7 How much fertiliser is needed?

(Source: *Soil Sense* C-06)

Product	**%K (total)**	**Milligrams of potassium per kilogram of product**	**100 kg/ha raises Skene potassium in micrograms per gram (µg/g) by:**		
			Sand	**Loam**	**Clay**
Muriate of potash (potassium chloride)	50	500	33.4	38.5	41.7
Sulphate of potash (potassium sulphate)	41.5	415	27.7	32.92	34.6
Nitrate of potash (potassium nitrate)	38.0	380	25.4	29.4	31.7

> *Excessive fertiliser application will increase your costs without improving production.*

Worked example

To raise the available potassium levels of a sandy soil from low to moderate using sulphate of potash.

From Table 6: the required level of potassium = 200 (using the higher figure in the 120–200 range).

Current level of potassium = 50, so, potassium needed = 200 – 50 = 150 µg/g of soil.

From Table 7: 100 kg/ha of sulphate of potash raises Skene potassium by 27.7 µg/g, so, sulphate of potash required = 150 ÷ 27.7 × 100 (kg/ha) = 5.4 × 100 = 540 kilograms of sulphate of potash needed per hectare.

When should potassium be applied?

This depends on the type of enterprise. Potassium fertilisers leach readily, and may also be taken up by plants in excess quantities. If high application rates are needed, it is suggested that more than one application over the plant's growing season should be applied to minimise potassium losses. This is especially true of perennial pastures and lucerne.

Potassium on crops is usually applied just prior to or at planting, and in horticultural situations it is usually applied as a NPK mix with each successive crop. Potash fertilisers can scorch crops if top dressed on damp leaves; however, plants usually recover quickly.

Note 1. Muriate of potash (potassium chloride) contains chlorine that may adversely affect soils and plants; however, some chloride in the soil solution is essential.

Note 2. Soils vary in their potassium content and its availability, depending on the rock type they were formed from and the coarseness of the soil particles. Fine soils hold potassium better than coarse soils and potassium can be leached readily from sands and soil organic matter.

What happens if adequate potassium is not applied?

Total potassium levels in soil are usually more than adequate, but most is not readily available to plants unless soil microbiology is active. If potassium supplies become the limiting factor, plants grow slower, become spindly and need more water for respiration. Seeds and fruit may become shrivelled.

8

Magnesium in the soil

Background

Magnesium is a metal element written using the chemical symbol Mg. It is one of a group of elements referred to as the cations. In soil it is always found in combination with other elements and molecules in the form of hydroxides, carbonates, sulphates and chlorides to name a few. In plants it plays an important part in photosynthesis, being part of the chlorophyll molecule. Magnesium in plants aids in phosphate metabolism, respiration, the activation of plant enzymes and in protein synthesis. It is also found in significant quantities in the seeds of many plants. Magnesium plays a vital part in the health of animals (including humans), particularly in conjunction with calcium and boron in bone formation, and in blood serum for metabolic processes.

Magnesium in the soil

Magnesium, in association with other cations, helps form soil structure by affecting flocculation of clay particles. In an ideal situation it should be in balanced ratios with the other main soil cations – calcium, potassium and sodium. The relative proportions are: calcium 65–70%, magnesium 15–20%, potassium 5% and sodium less than 5%. When these cation ratios are in balance the soil is likely to be soft and crumbly, allowing plant roots to freely grow in the soil and enabling soil biology to thrive.

If magnesium is present in excessive quantities, the clay tends to be very dense and hard with a prismatic or blocky structure, and is sticky when wet. This results in low hydraulic conductivity with water soaking into the soil profile only very slowly. High magnesium also limits the ability of plant roots to penetrate the clay, the roots often only travelling down the cracks between the clay prisms, with little if any movement into the clay prism itself (Figure 13 on p. 105). This obviously limits nutrient availability to plants.

Magnesium is capable of raising soil pH higher than calcium, and in an acid soil deficient in magnesium, application of magnesium oxide, magnesium carbonate or dolomite will help raise soil pH as well as correct a magnesium deficiency. It can also be applied in conjunction with calcium compounds such as lime (calcium carbonate), hydrated lime (calcium hydroxide) or quicklime (calcium oxide) to adjust cation ratios as well as raise soil pH. Magnesium can be leached reasonably easily from coarse textured acid soils and leaching is increased by nitrification and soils high in sodium.

Magnesium in plants

Magnesium is the only mineral found in chlorophyll and is actively involved in photosynthesis. A high proportion of the total magnesium found in plants is involved in regulating the pH level of plant cells and the anion/cation balance. It plays a key role in phosphorus transport in the plant and is involved in many enzyme reactions. If a plant is deficient in magnesium there will be impaired transport of the products of photosynthesis from the leaves to the roots. This initially shows up as mottling or yellowing of leaves between veins that remain green, or, in some species, interveinal chlorosis with reddening bordering the chlorotic zone. This is followed by growth of distorted young leaves and the plant appearing water stressed. Plant uptake of magnesium can be reduced by too much potassium, phosphorus or lime, or high applications of nitrogen fertiliser, leading to a state of induced magnesium deficiency.

Magnesium in animals

Magnesium plays a vital role in the health of animals, including humans. If animals graze pasture grown on magnesium deficient soils, they will have low blood serum levels of magnesium, which can lead to grass tetany (hypomagnesaemia) that if left untreated will be fatal in a short time from the onset of symptoms.

A chronic shortage of magnesium or boron can also lead to a number of conditions related to weak bones. Some other conditions directly related to magnesium deficiency are acetonaemia, arthritis, founder, osteoporosis, prolapse and respiratory ailments. Magnesium in a feed ration may calm hyperactive animals, and any condition that causes trembling or excessive excitability.

Magnesium is also involved in muscle maintenance and is useful to alleviate or prevent muscle cramps.

How to address magnesium deficiencies

Magnesium applications to soil should always be based on soil tests because it should be applied to achieve the desirable ratios with calcium, potassium and sodium. The soil testing laboratory should give a recommendation for application rates based on the test results.

There are a number of products that can be used to add magnesium as shown in Table 8.

Table 8 Magnesium fertilisers

Product	% magnesium
Dolomite	10–12
Magnesium oxide	40
Magnesium sulphate	20
Potassium magnesium sulphate	11
Magnesium chloride	11

These products are usually top dressed onto paddocks prior to or just after the autumn growth commences, or may be spread later in the season if crop deficiencies or animal health become an issue. There are also foliar spray products available that are usually based on magnesium chelates. These may be sprayed directly onto plants as required.

Stock may be given a supplement of dolomite as a loose powder or incorporated in a stock lick.

For urgent treatment of grass tetany, cattle may be given a subcutaneous injection of magnesium sulphate or the more modern treatment of powdered magnesium plus vitamin B_{13} tablets placed under the tongue, giving relief in minutes.

9

Trace elements in the soil

What are trace elements?

Trace elements are essential plant and animal nutrients that are required in very small quantities. They are often found in the soil in adequate quantities, but can become depleted over time if not replaced, or become unavailable if soil pH shifts too far either side of neutral. Trace elements can also become toxic if too much is present in the soil and available to plants. This can be caused by soil pH becoming too acid or too alkaline.

Why are they important?

Trace elements are required in the correct amounts by plants and animals for healthy growth. They are usually required as part of cell formation, or are involved in the regulation of plant and animal growth. Without them, these chemical processes do not function properly, leading to poor growth and increased susceptibility to disease.

Soil biological processes are also dependent on trace elements being available in the correct amounts for their growth, and if they are not available this can lower soil fertility, even when all other aspects of soil fertility are optimal.

The limiting factor concept

Limitations to plant and animal growth and health can often be determined by individual trace element deficiencies or toxicities when every other requirement for growth and health is present. This can also apply if too much of a nutrient is available that can either become toxic, or cause a deficiency of another nutrient due to an antagonistic effect. If this is the case, nutrient levels must be balanced to return the soil to a healthy state, which in turn can support healthy plants that will provide good food to grow healthy animals. Table 9 lists the most important trace elements.

Table 9 The more important trace elements

Element	Symbol
Boron	B
Chlorine	Cl
Cobalt	Co
Copper	Cu
Fluoride	Fl
Iodine	I
Iron	Fe
Manganese	Mn
Molybdenum	Mo
Selenium	Se
Silicon	Si
Sodium	Na
Sulphur	S
Zinc	Zn

Soil tests

One method of determining the state of trace elements in the soil is to do chemical soil tests. These tests allow the land manager to design a precise fertiliser program to fully meet the needs of the soil, plants and animals. Potentially this will result in better responses to applied fertilisers, and give better returns for invested capital and labour, and healthier animals.

Tissue testing

By testing plant tissue for nutrient content, deficiencies can be measured and a fertiliser program can then be developed to address any problems found. If this method is used, plant tissues must be collected from the correct part of the plant at the correct time of year.

Blood testing animals

Many animal disease conditions can be traced back to lack of one or more trace elements. This can be corrected by applying the appropriate trace element to the plants the animals are grazing as foliar fertiliser or soil fertilisers, or by direct supplement to the animal.

Deficiency or toxicity signs

Plants particularly, but also animals, can display visible signs of a nutrient either missing from their diet, or in excess. These signs often show as leaf discolouration, poor growth rates or poor animal health. For example, a plant that has too much of the toxin aluminium will have brown stunted roots, poor growth and show leaf yellowing (Figure 14 on p. 106). A plant with not enough potassium may have scorched leaf margins.

An animal fed excessive amounts of copper will have a damaged liver and will drop dead when stressed. If copper and selenium deficiencies are the problem, a steer may have a dull coat and possibly white scours as well. Boron affects bone growth and can lead to arthritis when deficient.

Signs of trace element deficiencies or toxicities

Often crops and pastures show clear signs if a nutrient problem is present, by colour changes or unusual growth patterns, or both. If more than one problem is present at a time these signs can be confusing, so quite a lot of experience is needed to make sound judgements on visual signs alone.

A safe rule of thumb is that if nutrient problems are present, the first check that should be done is to test soil pH, to ensure it is in the slightly acid to neutral range (pH 6–7). The second check should be to determine if soil physical conditions are suitable, for example, good soil structure, no hardpans, adequate drainage and sufficient soil moisture are present. As nutrient disorder signs can vary from one crop to another, it will be necessary to consult reference books to compare colour pictures with crop signs.

How to apply trace elements to crops

Trace elements are usually applied as components of a fertiliser mix, for example, super, lime and moly (molybdenum). They may be available from a fertiliser supplier as a standard mix, or may be mixed to special order to suit the needs of a particular farm. They are usually supplied in dry granular form, and applied at the time of sowing a crop or spread on a pasture early in the season. An alternative method of applying trace elements is to use foliar fertilisers, which are usually supplied as liquids, and sprayed onto growing crops or pastures. They are usually applied in a reasonably dilute mix, and may have to be applied more than once in a season.

What do they cost?

Bagged phosphatic fertiliser with trace elements adds about 10% to 20% to the cost of the plain fertiliser, depending on the trace element required. Horticultural mixes may not cost much more than the standard fertiliser.

Foliar fertilisers are expensive per litre, but less is needed because the plant can rapidly absorb nearly all that is applied, so the effective cost per gram of trace element per hectare is less. Note, however, that in hot weather they can cause leaf scorch if applied during the heat of the day. If trace elements are lacking in the soil, it is good business sense to apply them, because a relatively small outlay can often give spectacular returns (Figure 15).

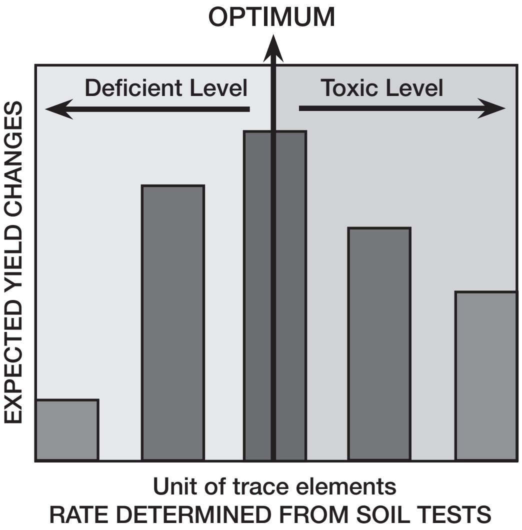


Figure 15 Effect of trace element availability on yields. (*Soil Sense* C-08)

10

Soil cations

What are soil cations?

A soil chemist will refer to cations, which are positively charged atoms, and anions that are negatively charged atoms or groups of atoms. Both these groups of charged atoms are found in the soil, and they react with each other to form chemical nutrients that provide food for plants. The soil cations are shown in Table 10.

Table 10 Soil cations

Name of chemical	Symbol
Calcium	Ca^{++}
Potassium	K^{+}
Magnesium	Mg^{++}
Sodium	Na^{+}
Aluminium	Al^{+++}
Hydrogen	H^{+}
Manganese	Mn^{++}

Cations and soil fertility

The soil cations play a large part in soil fertility, both in supplying plant nutrients, and in forming and maintaining good soil structure. Calcium and magnesium are essential for healthy plant growth and they are both required in reasonably large quantities. The potassium requirement is less than for calcium and magnesium. Sodium and manganese are required in very much smaller amounts and are quite toxic to plants if available in excessive amounts. Aluminium is not required at all by plants, but is toxic to plants in acidic soils.

Cations and soil structure

Three of the cations in particular have a profound effect on soil and subsoil structure. These are calcium, sodium and magnesium.

A soil with these nutrients present in the right ratios will often be granular and crumbly when moist. In other words it will be well structured as long as it is not damaged in other ways. This will allow easy movement of water and plant roots down into the soil profile. If too much magnesium is present in subsoil compared with calcium, the subsoil will tend to be very dense solid clay that can severely restrict water and root movement into the soil profile. If too much sodium is present, it will displace calcium from the clay particles, causing them to lose their crumb structure and slump together into a dense sticky mass when moist. These soils are referred to as sodic soils, and are generally inhospitable to plants. Often when plant roots encounter a sodic layer of soil, they turn and stay above it rather than penetrate downwards. The problems with sodic soil from a plant's point of view is that because the clay has slumped together so tightly, there are no air spaces to encourage plant roots to enter, and roots find the soil too strong to grow into because of the small pore spaces. Further, because there is a high sodium content in these soils, the osmotic mechanism plants use to access and transport nutrients in their sap does not operate well. Thus, a plant in sodic soil can show drought stress even when the soil is quite moist. Plants are also stressed simply due to the toxic effect of the salt (Figure 16 on p. 107).

Cation exchange capacity

This is a term often quoted in soil test results, and is a measure of the capacity of the soil to hold the major soil cations: calcium, potassium, magnesium, sodium and hydrogen (the exchangable cations).

'Cation exchange capacity' (CEC) is thus a measure of the ability of the soil to hold plant nutrients, and is an important measure of soil fertility. A high cation exchange capacity means a good supply of these plant foods are available in the soil. It is also important that the cations be in the correct ratio in the soil if plant growth is to be optimised.

What is a good range for cation exchange capacity?

Cations are attracted onto particles of clay and organic matter, and the extent of this attraction is dependent on the minerals present. This will vary from sands through to clay soils and according to the type of clay present.

Cation exchange capacity is expressed as milliequivalents (meq) of positively charged ions (cations) that can be adsorbed by 100 grams of dry soil. Table 11 shows CEC values for a range of soil types, which can be compared with farm soil test results. The higher the CEC value, the higher the potential fertility of the soil.

Table 11 CEC ranges for soil types

(Source: *Soil Sense* C-09)

Soil texture	CEC (milliequivalents per 100 grams)
Sand	5
Sandy loam	5–15
Loam	15–20
Clay loam	15–25
Clay	>30

Cation percentages

The ratios of individual soil cations to the total cations influence how well plants grow in the soil. The most desirable percentages for the cations are shown in Table 12. If the percentages of cations in a soil are different from the suggested percentages because of the origin of the soil (for example, the calcareous sands of the Mallee) it may be neither desirable nor economically feasible to try to adjust the cation percentages over the short term.

However, if significant soil problems are present that are seriously affecting production, then it may pay to check cation ratios with a view to improving them. (Refer to Chapter 3.)

Table 12 Desirable cation percentages in the soil

(Source: *Soil Sense* C-09)

Nutrient	Percentage of CEC
Calcium	65–70
Magnesium	15–20
Potassium	5
Sodium	<5
Aluminium	trace
Manganese	trace

How to apply soil cations

Calcium. Calcium is usually applied in the form of lime when used to raise soil pH, or as gypsum if used to help counteract sodicity. One tonne of lime per hectare will usually raise soil pH about half of one unit and help improve soil structure. Finely ground lime is best.

Gypsum may be required in rates between 5 and 20 tonnes per hectare to counteract sodicity and to make clay more friable. Gypsum can also be used to increase calcium in nonsodic soils.

Both additives may be top dressed on, but lime is best incorporated into the soil for faster results. Gypsum is most effectively applied dissolved in irrigation water but has to be mechanically mixed due to its low solubility.

Magnesium. If magnesium is required, it is usually applied as a top dressing of dolomite or magnesium oxide. This material will also raise soil pH, and its neutralising value is about 1.7 times that of lime. If pastures are deficient in magnesium, stock health may be adversely affected causing hypomagnesemia. Top dressing with dolomite or magnesium oxide will help solve this problem.

Potassium. Potassium is required by plants for cell growth, and it is involved in regulating plant water uptake and use, thus helping them cope with dry conditions. Potassium is usually applied in blended fertilisers, usually in conjunction with nitrogen and phosphorus, but can be added as a nitrate, chloride or sulphate. Potassium availability is dependent on soil conditions, and in excess it can be rapidly leached out of the root zone if it is not used. If high rates are required (for example by fruit trees) it is probably best applied in split applications to avoid leaching losses.

Sodium. This nutrient is not usually applied; rather, too much is the usual problem. Excess sodium may be leached out in time by fresh water if there is somewhere for it to leach to. Applications of gypsum are often used to help remove exchangeable sodium from the soil in conjunction with leaching. One situation where sodium may need to be applied is when growing plants in the beet family (for example, sugar beet and mangolds).

Aluminium. Again, the toxin aluminium is usually a problem of excess rather than deficiency. It is a problem in acidic soils, where it becomes soluble and available to plants. Addition of lime to reduce soil acidity above pH(w) 5.5 will solve toxic aluminium problems.

Manganese. The same applies for manganese as for aluminium; reducing soil acidity by adding lime will reduce its solubility, and toxic effects.

Hydrogen. Excessive hydrogen ions in the soil are an indication of the level of soil acidity. (pH is the number of hydrogen ions in solution.) Hydrogen is not added to or removed from soil, but is the result of chemical changes that happen in the soil from adding carbonates, oxides or hydroxides of calcium and/or magnesium, or from the results of microbial activity and root exudates.

11

Sulphur in the soil

Background

Sulphur is a chemical element and is written in the chemical form as S. Plants and animals require sulphur to build proteins that are important in the quality and quantity of plant material produced, and in the health of animals. Sulphur can give plants increased cold tolerance.

With the trend to high-analysis fertilisers that tend to be low in sulphur, deficiencies can occur in soil over time. It will then be necessary to add a sulphur rich fertiliser or gypsum to the soil at a rate indicated by a soil test to enable quality crops to be grown.

Sulphur in the soil

Most sulphur is concentrated in the organic matter in the surface layer of the soil; however, some is present in the subsoil where it has been deposited by leaching.

Sulphur combined with organic matter is not available directly to plants, but must be converted to the sulphate (SO_4) form by bacteria to be plant available. This happens best in warm, moist, well-aerated soil. However, when some bacteria are decomposing crop residues high in carbon, or when cold, waterlogged conditions are present, hydrogen sulphide (H_2S) (a gaseous product) is formed, which is lost from the soil. Sulphur availability in the soil can therefore be cyclic, changing from available to unavailable forms as soil conditions change.

Sulphur is removed from the soil by harvesting or grazing plants, and by leaching. As sulphur does not readily attach to soil and clay particles it is much more prone to leaching than phosphorus, calcium or magnesium, especially on sandy soils. It is also removed by erosion of topsoil by wind or water.

Sulphur may be added to the soil using sulphur rich fertilisers or gypsum and if near or downwind of industrial areas, rainfall may add significant amounts as acid rain. Some irrigation water may also contain sulphur, especially from some groundwater bores.

Sulphur in plants

Sulphur is present in every plant cell in association with nitrogen as proteins, and helps chlorophyll to be formed by the plant. It is also present in plant vitamins and enzymes. If sulphur levels are low then plant growth will be poor, resulting in slow growing, pale, spindly plants.

Sulphur deficiency symptoms

Young plants generally have a light green colour, are stunted, mature late, do not branch normally and are spindly. Grasses may show striping of the upper leaves. Deficiency symptoms may disappear later in the growing season as soil bacteria release sulphur previously unavailable to the plant. Deficiency signs may appear in legumes before they do in grasses.

Sulphur in animals

Cattle and sheep require sulphur to produce meat, milk and wool for the production of vitamins and the function of enzymes. It is present in muscle, cartilage, bone, tendons, walls of blood vessels, and is also found in bile and blood anticoagulants.

It is important in detoxifying many substances produced in the body. Sulphur also increases the feed conversion efficiency of ruminants by up to 25%, or conversely, lack of sulphur in the feed can reduce conversion efficiencies by up to 25%.

Soil tests

Laboratories can test for soil total sulphur, or plant available sulphur content. The total sulphur test is the quantity of sulphur that may become available over time, but not all of it is immediately available to plants due to the cyclic nature of sulphur availability.

The plant available test will show how much sulphur a plant could access at the time the sample was taken. This amount could change over time depending on the rate of organic matter breakdown, waterlogging conditions (less available) or warm, moist, well-aerated conditions (more available). Soils sampled as 0–60 cm samples may give a better prediction of likely responses to sulphur applications than topsoil sampling only.

Total sulphur is measured by x-ray fluorescence, and available sulphur by the ICP or CPC methods and may be quoted in micrograms/gram (µg/g) or milligrams/kilogram (µg/kg). Both of these are equivalent to parts per million (ppm). Pivot and Agplus analyses give different results due to different testing methods, so they need to be interpreted differently (see Table 13).

What do the tests mean?

Soil test results can be compared as shown in Table 13 where levels of plant available sulphur for two soil tests are used to decide the sulphur status of the soil.

Table 13 Assessing sulphur test results from two laboratories

(Source: *Soil Sense* C-04)

Level in soil (Blair)	**Agplus analysis**	**Pivot analysis**
	Available S µg/g	Available S µg/g
Low	<4	<6
Marginal	4–8	6–10
Moderate	9–12	11–50
High	>12	>50

If sulphur levels in soil are less than 9 µg/g, then the soil would probably benefit from the addition of sulphur fertiliser. If the soil is in a temporary state, such as containing rotting crop residue, or is waterlogged, then the problem may be self correcting over time when these adverse conditions disappear. Deep-rooted crops may also be able to access sulphur from the subsoil, and so may not respond to sulphur fertiliser.

A number of fertilisers and soil conditioners contain sulphur, as shown in Table 14.

Table 14 Sulphur containing fertilisers

(Source: *Soil Sense* C-04)

Carrier	**Chemical formula**	**Per cent sulphur**	**1 kg/ha of S requires: (kg of fertiliser)**
Ammonium phosphate sulphate	Varies	10–14	7.2–10
Ammonium polysulphide	Varies	36–45	2.2–2.8
Ammonium sulphate	$(NH_4)_2SO_4$	23.7	4.2
Ammonium thiosulphate	$(NH_4)_2 S_2O_3$	26 (60% aqueous)	3.9
Copper sulphate	$CuSO_4$	12.8	7.8
Epsom salts	$MgSO_4.7H_2O$	14.0	7.2
Iron sulphate	$Fe SO_4$	11.5	8.7
Gypsum	$CaSO_4 2H_2O$	18.6	6.0
Manganese sulphate	$MnSO_4$	14.5	6.9
Potassium magnesium sulphate	$K_2SO_4 2MgSO_4$	22.0	4.6
Potassium sulphate	$K_2 SO_4$	17–18	5.6
Sulphur, elemental	S	30–100	1.0–3.4
Sulphur dioxide	SO_2	50	2.0
Sulphuric acid	(100% H_2SO_4)	32.7	3.1
Superphosphate, normal	$Ca(H_2PO_4)_2+CaSO_42H_2O$	11.9	8.4
Superphosphate, triple	$Ca(H_2PO_4)_2+CaSO_42H_2O$	1.4	71.4
Urea ammonium sulphate	Varies	4–13	7.7–25
Zinc sulphate	$ZnSO_4 H_2O$	18	5.6

Note 1. Most sulphur fertilisers containing nitrogen tend to acidify the soil, so soil pH should be monitored regularly if using these fertilisers. Generally, for each kg of sulphur applied, 4 kg of lime will be needed to neutralise the acidifying effect. Elemental sulphur is particularly acidifying.

Note 2. Copper, manganese and zinc are trace elements, and as such will have an effect on the soil as well as the sulphur in the sulphate part of these fertilisers. These materials should be used with care.

Sulphur removal by crops

As crops are harvested, sulphur is removed from the paddock in the products. Removal will therefore deplete the sulphur left in the paddock for use by future crops (Table 15).

Table 15 Sulphur content of crops and pastures

(Source: *Soil Sense* C-04) *Figure 17 on p. 108.

Crop	% Sulphur	Pasture	% Sulphur
Barley	0.4	Wheat	0.4
Chick-pea	0.3	White Clover	0.3
Maize	0.3	Sub. Clover*	0.3
Lupins	0.6	Clycine	0.3
Navy Bean	0.25	Great Brome Grass	0.2
Oats	0.25	Green Panic	0.15
Canola	0.8–0.9	Lucerne	0.3–0.5
Rice	0.2	Medics	0.2–0.3
Sorghum	0.25	Phalaris	0.2–0.4
Sunflower	0.4	Ryegrass	0.2–0.4

How much sulphur fertiliser do I need?

If superphosphate containing 8.8% phosphorus (‘single super’) is being used regularly, it is unlikely sulphur deficiencies will occur. It is estimated that 12–15 kg/ha of sulphur (total elemental sulphur) is required for most crops and pastures.

Based on 15 kg of sulphur/ha/year, use Table 14 for sulphur fertilisers to decide a top dressing rate.

For example, from Table 14, for every 8.4 kg of normal superphosphate applied, 1 kg of sulphur is supplied. To apply 15 kg/ha of sulphur, 15 × 8.4 = 126 kg/ha. Therefore 126 kg/ha of normal superphosphate is required to supply the sulphur needs of this paddock.

When should sulphur be applied?

Sulphur is best applied when sowing crops, or in the early growth stages of pasture. For irrigated perennial pastures, a spring application, when the soil has warmed up, is best. Waterlogging caused by over irrigating will reduce the availability of sulphur to the plants, and may cause losses as gaseous hydrogen sulphide as a result of bacterial action in the soil. Over watering can rapidly leach sulphur down the soil profile. Canola crops are particularly sensitive to lack of sufficient sulphur.

What happens if adequate sulphur is not applied?

If a paddock has had a recent history of single super applications, it is unlikely sulphur deficiencies will occur for a number of years, unless the soil is very sandy. If sulphur levels are low then plant growth will be poor, with slow-growing, pale, spindly plants. Animals grazing sulphur deficient pastures will in turn have poor growth unless supplements are used. Crops will have low protein levels and legumes will not fix good quantities of nitrogen.

12

Aluminium in the soil

Background

Aluminium is a chemical element that has the chemical symbol Al. It is abundant in most soils as a component of clay particles. In neutral to alkaline soils, aluminium is almost insoluble, so is not available to plants (which, in fact, do not need it at all to grow well).

As soils become progressively more acid the solubility of aluminium increases and so the level of toxicity to plants increases. The most severe symptoms of aluminium toxicity occur in seedlings, presenting as poor root growth, with root tips and lateral roots turning brown, and often with an absence of root hairs. Field symptoms resemble phosphorus deficiency, as the effect of reduced root growth reduces the plant's ability to take up phosphorus from the soil (Figure 18 on p. 108).

Aluminium may also be concentrated in bleached layers of the soil in duplex soils.

Phosphorus fixation

In acid soils aluminium (Al) and iron (Fe) combine with phosphorus (P) to form insoluble compounds that are not available to plants. This means that in these soils applied phosphorus is quickly made less available to plants and phosphorus may become unavailable over time.

Figure 19 shows that at a soil pH of below 5.5 in water, aluminium starts 'complexing' with phosphorus, and its effect on phosphorus and its toxicity to plants rapidly increases as pH drops below 5.5. This may be compounded by increasing iron toxicity in acid soils. (In strongly alkaline soils, aluminium is not a problem, but calcium will make phosphorus unavailable.)

Treating aluminium toxicity

Aluminium toxicity in the soil can be overcome by increasing the soil pH by adding lime. The amount of lime needed can be determined by soil tests of topsoil to a depth of 20 cm. In soils that are acid at depth, it may be necessary to test down to 100 cm to fully understand the management implications.

Soil test results are expressed as exchangeable aluminium in milliequivalents per 100 grams of soil (meq/100 g) and calculated as a percentage of the cation exchange capacity of the soil (% CEC). The aluminium that affects plant growth is the aluminium in the soil solution.

Aluminium tolerance of plants

Some plants are more tolerant than others to toxic aluminium in the soil. In an acidic soil with high aluminium it is possible to carefully select species that are tolerant to high levels of aluminium. However, it is far better to reduce aluminium toxicity in the soil by liming as this extends the range of plants that can be grown economically. Table 16 shows a list of plants and their tolerance to aluminium.

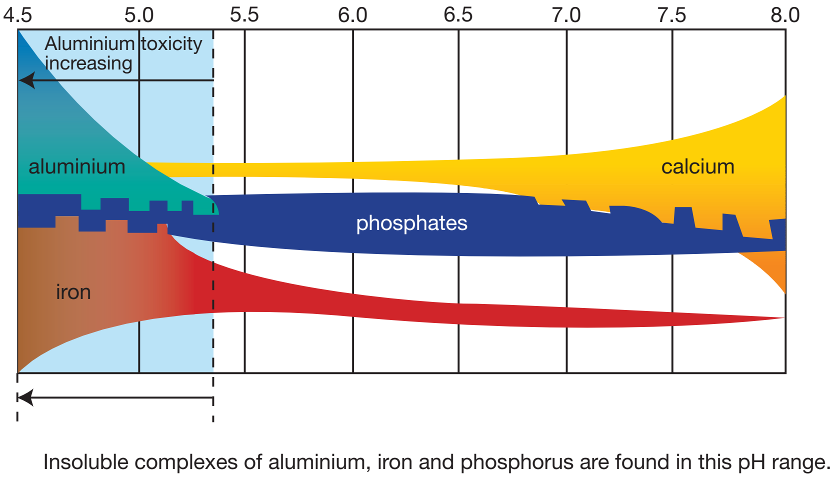


Figure 19 The effects of soil pH on aluminium. (*Soil Sense* C-07)

Table 16 The tolerance of crop and pasture plants to aluminium

(Source: *Soil Sense* C-07)

Species	**Level of exchangeable aluminium above which yields are reduced. (Aluminium percentage of CEC.)**	**Sensitivity**
Lucerne Barley Medics Canola	5	Highly sensitive
Red Clover Phalaris Sub. Clover Wheat	10	Sensitive
Woolly Pod Vetch Rose Clover Ryegrass Fodder Rape Some Oats Tall Fescue Cocksfoot	20	Moderately tolerant
Oats Triticale Cereal Rye Lupins Maku Lotus	30	Highly tolerant

Note. Within species, varieties can vary significantly in their reaction to aluminium toxicity. Generally, lucerne should not be sown when subsoil exchangeable aluminium is greater than 50 milligrams per kilogram, although this may depend on the cation exchange capacity (CEC) of the soil. There are interactions between calcium and magnesium in the soil that may allow lucerne to be grown, even if the exchangeable aluminium levels would seem to preclude the option. High levels of organic carbon can also reduce the toxic effect of aluminium on plants (Figure 20 on p. 109).

Summary

Aluminium toxicity in soil is directly linked to soil acidity, and fixing acidity problems will remove the aluminium toxicity. This is strongly linked to the type of farm enterprise and its management.

As a general principle, it is much better in the long term to control soil acidity, than take the option of planting acid-tolerant crops (Figure 21 on p. 109). The use of acid-tolerant crops alone as a management option will allow the soil acidity to continue to increase further over time, eventually leading to an irreversible loss of fertility and a breakdown of soil structure.

Regular liming will increase, or at least maintain, the range of crops that can be grown, thus increasing the farm's profitability and sustainability.

13

Soil sodicity

What is soil sodicity?

Sodicity is an expression of both the physical and chemical problems in soils resulting from an interaction between soil sodium content and the salt content of soil water. Sodicity has no clearly defined limits so that its effect on soil properties cannot be assessed based on the level of sodium alone, as the soluble salt level also has to be specified. Even small amounts of sodium can produce adverse effects if the soluble salt concentration in the soil solution falls below the level required (electrolyte requirement) for soil stability. For example, a combination of high sodium and low salt will produce extremely bad physical conditions in soils. Higher salt levels could avoid these soil structural problems but might impact adversely on plant productivity.

Some soils are more sensitive to sodium than others. This depends mainly on soil type, mineralogy, pH and organic matter. Generally a soil is considered sodic if the exchangeable sodium exceeds 5% of the cation exchange capacity.

How is sodicity different from salinity?

Sodicity is often confused with salinity. Salinity is an expression of the concentration of all the salts (electrolytes) present in soil or water and is commonly measured as electrical conductivity (EC). Salinity in Australia is dominated by sodium chloride (NaCl) or common table salt. While sodicity and salinity often occur together, the destructive effects of sodicity are only evident after leaching (washing out) of the soluble salts. While salinity affects plant productivity (by reducing osmotic uptake and toxic effects), sodicity affects soil by degrading its structure and reducing soil pore spaces, thus creating poor conditions for plant growth, and making the soil susceptible to surface crusting, erosion and growth of undesirable soil bacteria.

Soils affected by sodicity are referred to as sodic soils and soils affected by salinity are referred to as saline soils.

30% of the land area in Australia is comprised of sodic soils.

Definitions

Salt. A salt is an ionic compound made up of a cation other than hydrogen (H+) and an anion other than hydroxide (OH–).

Cation. An ion with a net positive charge. For example, a sodium atom (Na) can readily lose an electron to become the cation represented by Na+ (called the sodium cation).

Anion. An ion with a net negative charge. For example, a chlorine atom (Cl) can gain an electron to become the anion represented by Cl– (called the chloride anion).

Electrolyte. Substances that, when dissolved in water, results in a solution that can conduct electricity.

Soil salinity. The characteristic of soils related to their soluble salt content.

Soluble salts. Salts in the soil that are readily soluble in water. Such salts predominantly involve sodium chloride, but sulphates, carbonates and magnesium salts occur in some soils.

Soil solution. Soil water containing two or more dissolved substances. The substance present in smaller proportion is called the solute, and the substance that is present in larger amounts is called the solvent.

How is sodicity measured?

Sodicity assessment includes measuring the sodium content and electrical conductivity (EC) in both the solid and solution phases of soil. Sodicity problems in relation to sodium content are expressed as 'Exchangeable Sodium Percentage' (ESP) as a percentage of the cation exchange capacity.

Sodicity develops when the salts in a saline soil are washed down the profile, leaving sodium behind. This process can be quick (one year) or slow (over a period of a thousand years). A soil is considered sodic when sodium reaches a concentration where it starts to adversely affect soil structure. The sodium bound to clay particles displaces more useful cations such as calcium. The sodium weakens the bonds between the soil particles when wetted, resulting in clay swelling and dispersing (particles becoming detached). The dispersed clay particles can move through the soil, clogging soil pores. Both swelling and dispersion decrease the permeability of soils, thus reducing infiltration, aeration and drainage. The broken down soil particles in a sodic soil can be moved easily by water or wind erosion.

Solid phase. Soil particles, including organic matter, clay, silt, sand and gravel, mixed together to form a natural medium in which most plants can grow.

Solution phase. The aqueous phase of the soil and its solutes consisting of soluble materials and ions dissociated from the surfaces of the soil particles.

Figure 22 shows how a saline soil becomes a sodic soil.

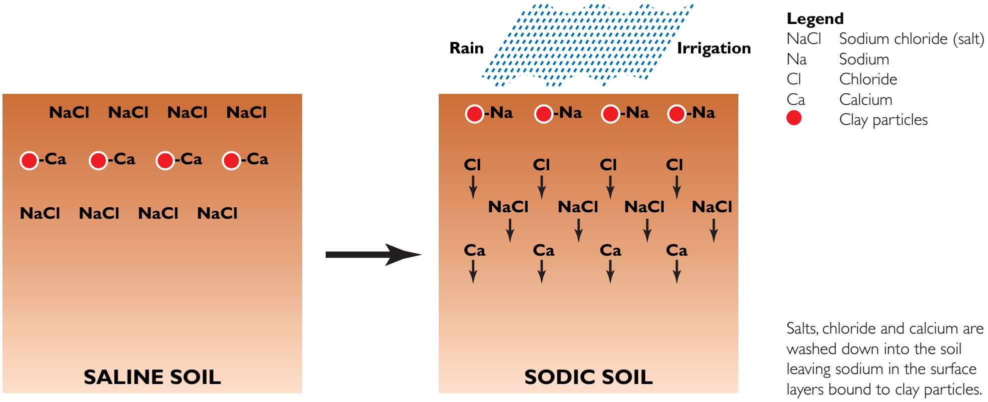
Types of sodicity

Inherent sodicity:

Soil sodicity resulting from the natural addition of sodium from cyclic salt and leaching of calcium displaced from clay colloids in saline soils (a long-term process).

Induced sodicity:

Soil sodicity resulting from the use of high sodium content irrigation waters (bore water or effluent) or as a result of sodic subsoil clay being brought to the surface or exposed by land forming (short-term process).



Salts, chloride and calcium are washed down into the soil leaving sodium in the surface layers bound to clay particles.

Figure 22 How a saline soil becomes a sodic soil. (*Soil Sense* C-12)

What are the symptoms of sodicity?

Symptoms that are typical of a sodicity problem include poor infiltration and drainage, resulting in waterlogging, increased water runoff and poor water storage; surface crusting; poor emergence of crops and pastures; and problems with cultivation and erosion. These symptoms might not always be due to sodicity. They may also occur on nonsodic soils caused by, for example, cultivation or compaction, or when exchangeable calcium is low and exchangeable magnesium is high. Soil tests for sodicity will usually identify the causes.

How to manage sodicity problems?

Sodicity problems can be corrected by the application of calcium salts, normally in the form of gypsum. In acidic-sodic soils, lime may be applied either alone or in combination with gypsum. The sodium displaced from the clay particles by calcium comes back into the soil solution and is likely to move deeper in the soil by leaching. Once this is achieved, it is a matter of (1) maintaining salt (preferably Ca salts) concentration in soil solution to a level that will prevent the clay from swelling and dispersion, and (2) minimising sodium inputs to soil to prevent further problems. Figure 23 shows how a sodic soil is transformed into a nonsodic soil.

What are the sodium inputs to soil?

Most of the Australian landmass has been under the sea at least once. Following geological movement the sea floor has become dry land. Because of this, a great deal of sea salt is present in Australian soils. Most of this salt has leached down the soil profile until it reaches a point where there is insufficient soil moisture to leach it further.

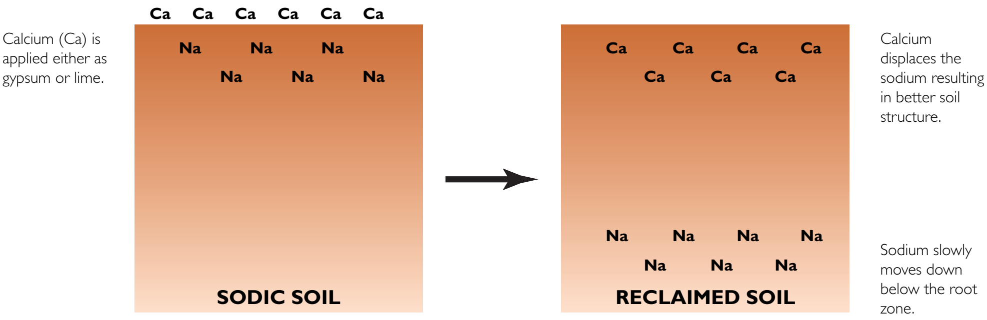


Figure 23 Effect of adding a calcium fertiliser to a sodic soil. (*Soil Sense* C-12)

The salt load will stabilise at this level unless there is a reduction in vegetative cover, which will then allow more water into the soil and the salt will be leached further, either downwards or sideways along aquifers. Other salt inputs to the soil are through salt blown in from the sea, saline groundwater, irrigation water (bore water or effluent) and dissolution of sodium-bearing minerals in the soil itself. Minor inputs are through rain and the application of chemicals or fertilisers containing sodium.

What are the soil tests for sodicity?

Soil tests that are routinely done to assess sodicity problems are:

- exchangeable cations to calculate exchangeable sodium percentage
- soluble cations to estimate the sodium absorption ratio (SAR)
- exchangeable cations to estimate exchangeable sodium percentage (ESP)
- electrical conductivity (EC) to estimate soil salinity
- Ca/Mg ratio
- clay dispersion
- organic matter content
- texture.

14

Soil analysis results

The way soil analyses are reported will vary from state to state and between laboratories within a state. A reputable laboratory will use test methods in accordance with the Australian standards and will be able to produce repeatable results from samples tested.

The chosen laboratory should be properly accredited and their reports are written to meet the client's needs. Once a laboratory is chosen it is better to stick with it rather than switch from one to another, as this makes it easier to compare individual paddock results over a number of years.

Soil sample preparation

When submitting a sample for testing, the lab will ask for basic information to identify the client, the location where the sample came from, previous fertiliser history of the paddock, and the ongoing or proposed land use for the area being tested. They will also ask for the sampling depth, for example, 0–10 cm. Bearing in mind that laboratories may process thousands of samples, it is important that each sample sent for testing is clearly labelled, so it can be accurately identified as it goes through the testing and reporting procedure.

The laboratory report

(1) *Colour and texture*. Soil colour and texture will be shown, for example, grey-brown clay loam. Some labs may use the new Australian Soil Classification terminology that more precisely specifies a soil according to its chemistry, for

example, Sodic Mesotrophic Yellow Dermosol. (At this stage this terminology is probably more useful to soil scientists than farmers.)

(2) *Soil pH*. The pH describes the level of acidity or alkalinity of the soil, with 1 being extremely acid, 7 being neutral and 14 being extremely alkaline. The tests will be done with either one part of soil in five parts of water, reported as pH water, or as one part of soil in five parts of dilute calcium chloride solution reported as pH $CaCl_2$. A good report will also specify the desirable pH level for the crop to be grown.

(3) *Electrical conductivity* (*EC*). This is a way of measuring how much salt is in the soil. As salty soil conducts an electric current better than a soil without salt, the higher the conductivity reading, the saltier the soil. This is an important reading as many crops have a low tolerance to salt (see 'Total soluble salts' below).

The unit of measurement is microsiemens per centimetre or decisiemens per metre.

(4) *Total soluble salts* (*TSS*). This is a measure of all the soluble salts in the soil, including water soluble plant nutrients, and will be measured in parts per million or milligrams per kilogram.

Nutrient elements

Nutrient elements may be measured as plant available or as total amount of the element present in the soil. The amount of each element actually available to the plants will vary with soil pH, so when considering fertiliser programs it is best to get the pH right first if possible, before adding other nutrient elements. Modern thinking is that the soil cations should also be brought into balance before adding other nutrient elements. These consist of calcium, magnesium, potassium, sodium and, in acid soils, hydrogen, aluminium and manganese.

Nutrient elements are measured in parts per million (ppm), milligrams per kilogram (mg/kg) or milliequivalents per 100 grams of soil (meq/100 g). They may also be expressed as a percentage of the soil. Irrespective of the way they are written, a good soil report will show the desirable level in the same units, so it is easy to see if more is needed or if there is too much of a particular element.

(1) *The soil cations*. These consist of calcium, magnesium, potassium, sodium, hydrogen, aluminium and manganese. In a soil report the quantities present will usually be expressed as the plant available amount. The exception is hydrogen that determines soil pH. A good soil report will show the amount of the cations present and a recommended level for the crop for that site.

(2) *Cation exchange capacity* (*CEC*). This refers to the capacity of the soil to hold the cation elements, and is a measure of the potential nutrient reserve in the soil and thus an indicator of soil fertility. An imbalance of soil cations, especially calcium and magnesium, can cause soil structural problems and high levels of

aluminium and manganese can be toxic to plants. Cation exchange capacity is measured in milliequivalents per 100 grams (meq/100 g) and the higher the number, the more plant nutrients should be available.

(3) *Organic carbon and organic matter* (*OC and OM*). These measurements give an indication of animal and plant residue and microflora and fauna in the soil such as fungi, bacteria and so on. Australian soils are often low in OC and OM due to the hot dry summers and autumns that tend to burn carbon from the soil and push the living bacteria and fungi into survival mode only.

Usually, the higher the OC and OM levels in the soil: the more porous the soil is, and the better it will support plant growth and moisture retention. OC and OM are measured as a percentage of the soil.

(4) *Nitrogen*. There are two forms of nitrogen in soil: nitrate N that is inorganic, and ammonia N that is organic. Nitrate N refers to soluble nitrogen salts and ammonia N shows the amount of N present due to biological activity in the soil. Nitrogen quantities are usually expressed as 'parts per million' (ppm), milligrams per kilogram (mg/kg) or as a percentage (%). The amount of N present in a soil will vary over a 12 month period due to biological activity and soil moisture levels.

(5) *Exchangeable sodium percentage* (*ESP*). This is the amount of sodium present in the soil measured as a percentage of the cation exchange capacity (CEC).

Note. Sodium in the soil is not the same as salt that causes *salinity*, whereas sodium causes *sodicity*. In this case a low reading is best as an imbalance of sodium in the soil adversely affects soil structure and plant growth in species intolerant of sodicity. Zero to 5% sodium is considered good, 6–15% is moderate sodicity and greater than 15% is high sodicity. Some soil reports will also show an adjusted CEC that is more closely related to plant responses than the raw figure. Sodic soils may respond to treatment with gypsum to displace the sodium from the clay particles and replace it with calcium.

Recommendations in soil reports

Most soil reports will now give recommendations for fertiliser and /or soil amendment applications. These may be in the total quantity of a product such as gypsum or lime, or the amount of a nutrient element required.

If this is the case, a calculation is required to determine the application rate of the product being used compared to its nutrient content. For example, urea is 46% nitrogen so if 50 kg of N is required per hectare, then approximately 110 kg of urea is required per hectare.

If products such as MAP (mono-ammonium phosphate) or DAP (di-ammonium phosphate) are used that contain more than one nutrient element, they may have to have another fertiliser added to them as a mixture to apply the right ratio of nutrient elements.

If high rates of lime are part of the recommendation, then the lime should be applied first and other nutrients later on to avoid nutrients being made unavailable to the plants. Very high rates of lime should be applied in split applications to avoid a period of poor plant growth. Trace elements may be applied as part of the main fertiliser in a product blend or separately as a foliar spray.

15

Encouraging soil biological activity

Why is soil biological activity important?

Soil is a living entity in its own right, and as such can be in good or poor health. A healthy soil leads to healthy plants due to better nutrition and reduced risk of disease, which in turn leads to healthier animals that graze on those plants. A healthy soil is more productive, which helps improve farm viability. A healthy soil is also less prone to damage than a soil that is already suffering from some degradation from poor management.

What is soil biological activity?

Soil biological activity refers to the living aspects of the soil, which includes the large, small and minute life forms in the soil. These life forms include animals such as earthworms and springtails, fungi such as the hyphae of mushrooms and toadstools, actinomycetes and mycorrhizae, and bacteria such as rhizobia.

There are many other animals and micro-organisms that live in the soil and give the soil its biological diversity, which determines in part how well plants can grow in it. In a healthy soil there is a balance between these life forms that make the soil eminently suitable for supporting plant growth.

Undesirable balances are also reached between life forms in a soil that is not so healthy, which may encourage the increase of pathogenic (disease causing) organisms. A reduction in the rate of nutrient cycling, from available to unavailable forms, can also occur.

The biological properties of soil are constantly changing due to the temperature and moisture changes in the soil, and they are also affected by soil pH levels. In favourable conditions, soil biological activity can increase rapidly, and likewise, if conditions become unfavourable, then soil biological activity can shut down as the soil conditions become less conducive to their growth.

> *The amount of plant growth on top of a soil is directly proportional to the biological activity in the soil.*

How can soil biological activity be encouraged?

Soil organisms basically like the same soil conditions as plants; so by creating good conditions for plant growth, biological activity is also encouraged. There are a few basic requirements that can be listed.

- The soil needs to be moist, neither too dry (dusty), nor too wet (waterlogged).
- The soil needs to be warm. The ideal temperature is between 15 and 25°C.
- The soil pH ideally needs to be close to the neutral range; say between pH 6.0 to pH 7.5. This range allows many important chemical reactions to occur in the soil, and is not harmful to the growth of the soil organisms.
- There needs to be an adequate food supply for the organisms to live on. Organic matter, such as dead vegetation, compost, animal dung, dead insects and so on, is all good food for them. Like us, they cannot live without adequate food.
- There should be no chemical toxins, such as insecticides, miticides, some herbicides, fungicides, and animal medications (from urine) such as anthelmintics or antibiotics.

Table 17 lists a few do's and don'ts that will help encourage soil biological activity.

Table 17 Encouraging soil biological activity

(Source: *Soil Sense* B-02)

Do this	Do not do this
Keep pH in the desirable range.	Graze the soil surface bare.
Keep soil loose and friable (rip hard layers).	Apply chemicals unnecessarily.
Provide good drainage to prevent waterlogging.	Use long fallows with bare soil.
Minimise applying chemicals to the soil.	Burn stubbles.
Manage soil nutrients for optimum plant growth.	Allow soil to become too acid.
Use rotational grazing to spell paddocks regularly.	Deplete soil nutrients by using more nutrients than are replaced.
Use stubble retention practices when cropping.	Use high stocking rates on wet soils.
Use minimum tillage practices when cropping.	
Rotate crops to avoid disease build-up.	
Improve microclimates by using tree rows.	
Maintain plant cover as mulch on the soil surface. (Do not overgraze).	
Avoid soil compaction by reducing trafficking by stock and machinery.	
Use perennial pasture species with a good mix of plant species and cultivars.	
Top dress with lime to keep the soil in the correct pH range (if necessary).	

Just like us, soil organisms need food, water and warmth to thrive.

Benefits of managing soil biological activity

The benefits of encouraging soil biological activity are that the farm will be more productive and sustainable.

- Crops and pastures will be healthier due to fewer disease problems and better nutrient cycling in the soil, leading to better plant growth.
- Animals will be healthier, because the plants they feed on will have better balances of nutrients, meaning the animals in turn will not be deficient in vital nutrients. If animals have an adequate supply of all necessary nutrients they are much less prone to disease and will grow faster.
- Animals will provide better food for human consumption.
- There will be a reduced need for costly chemicals, and in an organically managed farm, chemical use may be nil. This may lead to lower gross returns, but higher net returns, making the farm more profitable. The effect that this has on downstream costs such as human healthcare is unknown, but is likely to be very beneficial.

> *Human health is dependent on the quality of the food we eat – that ultimately depends on the soil that produces the food.*

16

Earthworms

Background

For many years the beneficial effects that earthworms have on soil fertility have been known, but it is only relatively recently that earthworms have been studied in Australian soils.

Each country has its own native species of earthworms, some of which are quite adaptable, and have spread to other countries. Australian soils now contain native species and a range of introduced species that have adapted to our conditions, and in many cases have displaced the native earthworms. The longer, thinner, introduced earthworm and the shorter, stockier native earthworm are now both present in south-east Australia.

> *As earthworms respond rapidly to changing soil conditions, they can be useful as biological indicators of soil health.*

Soil requirements for earthworms

Soil pH

Earthworms prefer a soil pH(w) range between 4.5 and 8.0. Most species cannot survive in useful numbers in highly acidic or alkaline soils, although there are species that have adapted to local conditions outside the above range.

Calcium

Earthworms require calcium in their diet and cannot live in calcium deficient soils. If soils are low in calcium, adding lime encourages earthworms.

Water

Earthworms need water to keep their skin moist to breathe. In dry times they may burrow deep in the soil to allow them to hibernate until soils become moist again.

Air (drainage)

Although earthworms require moisture, good drainage is also important to allow them to breathe. In waterlogged conditions, earthworms will come to the surface for air.

Organic matter

Earthworms feed on organic matter, so soils low in organic matter cannot support a good earthworm population. Burning stubble reduces available food for earthworms, and practices such as maintaining perennial pastures, direct drilling crops and stubble mulching help maintain their food supply.

Uncompacted soils

Soil compacted by stock, machinery or farm management practices discourage worms as they find it hard to burrow through dense soil. Compacted soils waterlog more easily and have less air available, which further discourages earthworms.

Soil free of dangerous chemicals

A number of farm chemicals can reduce or kill off worm populations in the soil. Fertilisers that acidify the soil, such as ammonium sulphate, anhydrous ammonia, DAP and so on, reduce populations and copper-based fungicides and residues from stock drenches (passed out in dung or urine) will kill earthworms.

Useful species of earthworms for farms

Not all earthworms are suitable for pasture or crop paddocks (see Table 18). The ‘tiger worms’ found in compost heaps require more organic matter than is usually found in paddocks, so are not likely to survive in field conditions.

Table 18 Earthworm species found in farm soils

(Source: *Soil Sense* B-01)

Species	Pasture	Crop	Burrowing habit
Aporrectodea rosea	yes	yes	To 10 cm
Aporrectodea trapezoides	yes	yes	To 20 cm
Aporrectodea caliginosa	yes	yes	To 20 cm
Microscolex dubius	yes	yes	Not very active
Microscolex phosphoreus	yes	yes	Not very active
Lumbricus rubellus	yes	no	Under dung pats

Note. All of these worms are found in lower rainfall (less than 600 mm/pa) pasture and cropping soils.

Why bother with earthworms?

Earthworms recycle plant nutrients in the soil thus making them available to plants, and also improve soil structure and drainage. Their casts form stable aggregates that improve the crumb structure of soil and they form channels in soil that plant roots can follow and that assist soil aeration and drainage. Earthworms incorporate plant litter into the soil and help release plant nutrients, aiding plant growth. They are useful as biological indicators of soil health.

How to increase earthworm numbers

- Manage the soil to provide their food, water and physical requirements.
- Add lime to acid soils, or soils deficient in calcium.
- Transport worms from areas that have good numbers. Remove small spades full of turf from good areas and place the turf upside down on a 10 metre grid on the area to be seeded when conditions are moist. It would help if the area had recently been limed. The earthworms will fully colonise the new area in six to seven years if conditions remain suitable.

How many earthworms is enough?

Worm numbers can be checked easily by digging about 20 shovels full of soil over the area to be checked.

Crumble up the soil from each shovel full and count the worms, then divide by the number of shovels full to get the average number. As a guide:

0–2 worms per shovel full	poor
3–5 worms per shovel full	good
>5 worms per shovel full	great!

Source: *Soil Sense* B-01

17

Biological farming

Background

All farming is ‘biological’, in that crops and pastures are produced from soil and are used to feed and clothe people. Some farming systems use ‘natural’ inputs such as organic fertilisers including compost, seaweed, animal manure, biological cultures and so on (organic and biodynamic farming), while others choose to use manufactured fertilisers, herbicides and pesticides (conventional farming).

There is much disagreement between the proponents of these systems as to which is best. There is no clear answer in absolute terms, and each side can produce compelling arguments as to why their system should be used, with some farmers opting for a hybrid system built on the best of both systems.

Both systems in their own way rely heavily on the natural cycle of birth, growth, death and recycling of the remains, and all the complexities of the biological processes that make this happen. The conventional interpretation of biological farming, however, is a system that relies on maintaining or increasing soil fertility using plant or animal residues and other naturally available inputs to supply nutrient elements for future crops, often in a cyclic way. Of course, it is not as simple as just that, as there are many other issues such as soil management, crop rotations, biological enhancement of the soil, pest and disease management, and not destroying the environment with toxic chemicals.

The concepts of biological farming

(a) Soil fertility

Biological farmers will maintain or improve soil fertility using systems developed by observing how this happens naturally without human intervention. These principles are then used to farm the soil to produce the crops and animals required.

A lot of their success is based on managing the microbial life in the soil, using crop rotations to best advantage, and managing soil water through building high humus levels in the soil.

(b) Soil nutrients

Major soil nutrients such as nitrogen, phosphorus, potassium and calcium are supplied from inputs such as animal manure, nitrogen from legumes, composted plant and/or animal products, green manure cropping, fish meal and seaweed products, and crushed rock minerals. Minor nutrients and trace elements are supplied by mixtures of crushed minerals, wood ash and so on, and releasing inorganic nutrients already in the soil using biological additives.

One very important soil nutrient is humus, and every effort is made to keep humus content in the soil as high as possible. This is critical in maintaining soil microbiology, and soil structure. Organic farmers will also do their best to recycle soil nutrients, and, in a closed system, all products such as grain, meat, fibre and the like, which is removed from an area, will eventually end up back on this area for use by future crops. Humus has the ability to hold soil water and make soil nutrients available to plants that would otherwise be locked up and unavailable.

(c) Crop rotations

Often a biological farmer will closely observe the soil, and based on these observations will let the soil tell them when a change of crop is needed. This may be based on current crop yield, plant species present such as indicator plants and weeds, soil physical condition such as crusting or compaction, and soil biological health. A decision will be made on the picture formed from all observations, and not on one or two inputs only.

In terms of horticultural production (such as vegetables) the tried and proven crop rotations developed over centuries are used. A very basic rotation is as follows: manure the soil, heavy feeding crops (greens or leaf crops), then root crops, then lime the soil and follow with legumes, then back to leaf crops. The main thing is to balance plant nutrient needs, and not grow plants from the same family more than once in the full rotation. The exact rotation use will vary with marketing needs and climatic factors. For example, in cold regions, winter crops are not particularly successful, whereas in the subtropics, crops can be grown all year round.

(d) Pest control

Use is made of natural pest control using pest traps, predator insects or microbiology to bring pests into an acceptable balance rather than blitz them completely with strong chemicals. By doing this, biological farmers will accept a degree of crop loss or crop damage in the belief that the produce that is harvested is of superior quality. Some pesticides used are: Pyrethrum, Neem oil (that will kill predators as well as pests), pheromone baits, and milk can be used as a fungicide. The other aspect of pest control is that if soil nutrients are in balance and the plant is healthy, then often pest attack is minimal and other control measures are not necessary.

(e) Permaculture

A permaculture system is designed to integrate climate, soil, water, plant and animal interrelationships and a range of plant types that can benefit each other's growth. The designs include animal and aquatic production in an integrated system where plants benefit animals and animals benefit plants. Production per hectare can be very high in total but can also be very labour intensive.

(f) Companion planting

Companion planting designs make use of characteristics of one plant (for example garlic), which if planted near another plant (such as apple trees) can help reduce pest attack. Plants that compliment each other in a culinary sense often grow well together as well, such as basil and tomatoes. The concept is that a synergy develops between carefully chosen plant species when planted close to each other, thus increasing the production of both.

(g) Biodynamics

The principles of 'biodynamic farming' were developed in European climatic and soil conditions and include the use of microbial products such as 'Product 500' and by increasing soil energy levels. A skilled user of the biodynamic system can achieve sustainable high production of quality produce. The system is hard to quantify using current scientific methods, but this is not to say it is not effective. While it was developed in a cooler and moister climate than most of Australia enjoys, it will still work in the harsher Australian conditions. If using this system, care must be taken to keep both aerobic and anaerobic organisms in the proper balance, because if anaerobic organisms are neglected, the system can suffer 'burn-out' over time. With all the farming practices mentioned here, if produce is exported off the farm then there is the risk of the inorganic nutrients becoming depleted and deficient for the plant's needs. Regular soil testing to monitor nutrient levels will show if some nutrients need to be replaced for use by subsequent crops.

(h) Organic additives

There are a large range of specialist organic additives available on the market, most of which claim to improve soil, plant and animal health significantly. The point to remember before using these products is to get the soil basics, such as soil nutrient balance and soil physical characteristics, right first. As many of these products can be very expensive per hectare treated, it would be wise to try a small trial area to assess any economic benefit before treating large areas. Lifting soil health and productivity from a relatively low level as in a damaged soil should be done in stages, and generally the organic additives are best used later in the improvement sequence for best results. Another important point is that many of these products are based on living organisms, and, if spread in the field when conditions are not suitable, such as hot dry weather, the organisms may not survive at all, or at best be severely depleted in numbers and not give the benefit hoped for. Any label instructions should be followed closely for best results.

(i) Weed control

In organic farming, weed control is done by crop or pasture management to reduce weeds that would affect the following crop, cultivation rather than chemical control, and techniques such as flame weeding. In horticultural cropping, cultivation in conjunction with hand weeding is often used together with mulching. Newer techniques becoming available are cultures of soil organisms that can target specific species such as grasses and not damage the crop being grown. Again, an organic farmer will manage soil according to what is growing on the soil, which may significantly influence the need for weed control for future crops.

(j) Bioextraction of heavy metal contamination

Over time, previous land use techniques have left a legacy of soil and water contamination by herbicides, pesticides (including the very stable organo-chlorides such as DDT) and heavy metals such as arsenic, cadmium, lead and mercury. There are many examples where large areas of land, such as in Iowa and California in the USA, are severely damaged to the point that it is questionable whether farming should continue on such land. It should be remembered that if the soil is poisoned, the crops and livestock growing on that soil can be poisoned. If they are then used for human food, they can poison us as well, as we are at the top of the food chain.

Some chemicals can be taken up in significant quantities by specific plants, and if these plants are grown as a crop and harvested, soil levels of the chemical can be reduced. If the contaminated crop is then processed, the chemical(s) can then be recovered for use, or responsible disposal elsewhere.

Summary

Biological farming is a blend of the art of farming and science, and is gaining in popularity because the extent of the environmental damage caused by chemicals and pollution is becoming too serious to ignore. People are trying to develop systems of farming that will produce the food and fibre needed to feed and clothe the global population in a sustainable way. The reliance on fossil fuel energy and chemicals is clearly doing immense environmental damage, and the system primarily used at present is running down food producing resources globally. Often with the current system of farming, it costs more energy to produce food (energy inputs) than the energy in the food produced (energy output). This is clearly not sustainable.

Countries such as China, for example, have been producing food from the same land for thousands of years using the cycling of nutrients method, without the use of chemical inputs, or even fossil fuel energy. This has been made possible because of the very large labour force available, and their willingness to recycle so-called waste products.

Before the Spanish invaded South America, the native South American Indians had a well-developed system of soil management based on addition of carbon (charcoal) and bacterial cultures, the remains of which are still evident today in Brazil. There is evidence where the leached tropical soils of the time have been converted to deep (10 metres) rich black soil capable of growing excellent crops that fed their very large population.

18

Components of soil fertility

What is soil fertility?

Soil fertility is the ability of the soil to sustain healthy plant growth. Some soils are inherently more fertile than others, and, although soil fertility can be changed by poor and good management, generally soils have an upper limit on how fertile they can be on a sustainable basis.

Factors affecting soil fertility

Cation exchange capacity

A high cation exchange capacity means that the soil has a good supply of nutrient elements available for plants.

It is important that adequate amounts of each plant nutrient are present, or else the nutrients in short supply will limit plant growth. These nutrient elements can be divided into major, or macronutrients that are required by plants in large amounts, and trace, or micronutrients that plants require in small quantities, but they are nevertheless essential for healthy plant growth.

Cation exchange capacity refers to the amount of plant nutrients available in the soil.

Table 19 The main essential plant nutrients

Macronutrients	Chemical symbol	Micronutrients	Chemical symbol
Nitrogen	N	Iron	Fe
Phosphorus	P	Manganese	Mn
Potassium	K	Copper	Cu
Sulphur	S	Zinc	Zn
Magnesium	Mg	Boron	B
Calcium	Ca	Molybdenum	Mo

Nutrients in the soil may be taken up directly by plants, or nutrients may be accessed by soil organisms and thus made available to plants indirectly. Where there are insufficient nutrients available to meet the needs of the plant, nutrient deficiency symptoms can develop. This may occur when nutrients are leached out of the topsoil down beyond the root zone of the plants.

However, plants growing in soil with adequate essential nutrients present may still suffer from a deficiency of one or more elements. This is because some of the nutrients present may be in forms that are unavailable to the plants, as chemical reactions in the soil have changed them into insoluble compounds. Nutrients may also be tied up within soil particles, and are physically unavailable to plants.

Leaching

A soil may start off with an adequate supply of nutrients, but they may be leached down the soil profile and become inaccessible to plant roots. This is especially true for sandy soils in high rainfall areas. In comparison, heavier soils do not leach as readily, and in areas of relatively low rainfall there may be little, if any, leaching, especially when good plant cover is present.

Heavy rainfall events during normally dry times of the year can lead to nutrient losses by runoff as well as leaching.

Soil structure

Soil structure is related to the sand, silt, clay and organic matter content of the soil and its ability to form aggregates. A soil with good structure will have soil particles formed together to form stable aggregates. These aggregates can be quite stable over time, especially in a soil with a high organic matter content, although some aggregates can be fairly fragile and easily broken down by machinery or stock pressure, especially when wet. Stable aggregates provide the framework for soil voids that allow easy entry of air, water and plant roots. They also provide areas in which the soil's macro- and micro-organisms can thrive. Poor structure is inhospitable for plant growth and leads to waterlogging and plant diseases (Figure 24).

Structural stability in soil is greatly enhanced by high levels of organic matter, which can be achieved by minimum, or no till cropping, appropriate rotations and use of perennial pastures. Management practices that encourage soil biological processes lead to good soil structure.

> *Organic matter adds plant nutrients and structure to a soil, and provides food for plants and soil organisms.*

Organic matter

Organic matter gives soil its dark colour and provides many plant nutrients, especially nitrogen and carbon, and significant quantities of many other nutrients. Organic matter also provides food for soil macro- and micro-organisms, which in turn decompose it and release the nutrients in forms that are available to plants. The soil organisms themselves decompose after they die, releasing nutrients to plants in a slow release form. Organic matter is a major contributor to forming and maintaining a stable, well-structured soil. A highly fertile soil will have high levels of organic matter and a reduced need for supplementary chemical fertilisers. A further benefit of organic matter in soil is to increase both the water infiltration rate and water holding capacity of the soil. This means that there is less runoff during a rainfall event, so more water is available in the soil for plants to use (Figure 25).

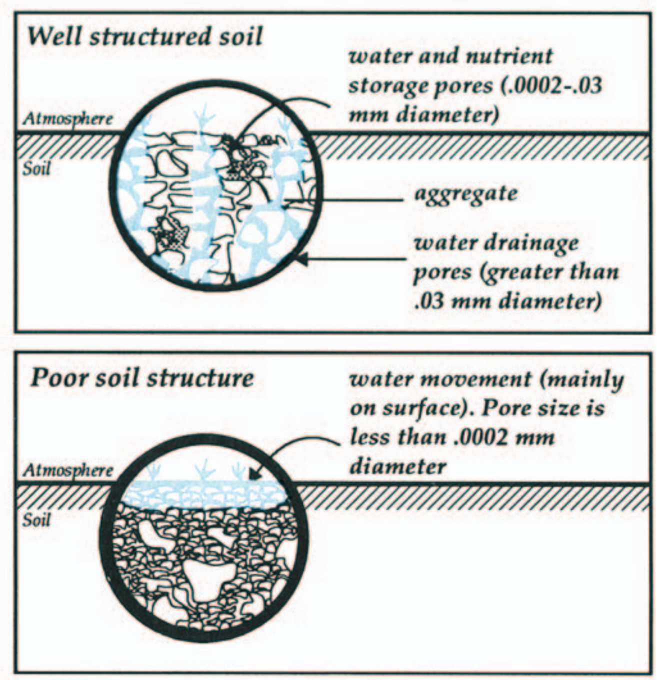


Figure 24 Well-structured soil (top) and poorly structured soil (bottom). (*Soil Sense* M-03)

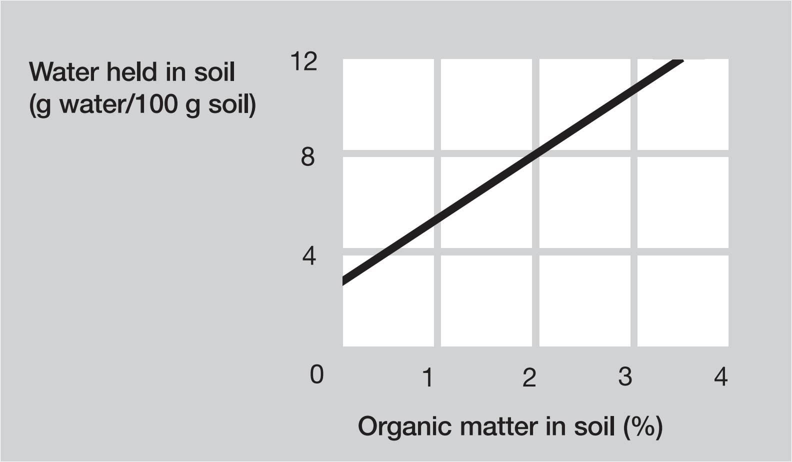


Figure 25 Dramatic effect of increasing organic matter content on water held (at field capacity) in a very sandy soil (Mt Burr sand from South Australia). (*Soil Sense* M-03)

A fertile soil is a basic requirement for a viable farm.

Water holding capacity

Plant growth is highly dependent on adequate water supplies in the soil. Sandy soils have very poor water holding capacities because most of the soil pores are large and drain readily. Clay soils, on the other hand, have many fine pores that give clay soils their good water holding capacity. The amount of water available for plant use has a large effect on soil fertility. Infiltration of water into the soil is also dependent upon its soil structure, and in poorly structured soil much rainfall can be lost as runoff. This can represent a big loss of productive capacity in lower rainfall areas. On the other hand, nutrients can leach out of sandy soils in high rainfall areas, thereby reducing the productive potential of crops and pastures.

Table 20 Infiltration rates for different soils

(Source: *Soil Sense* M-03)

Soil texture	**Infiltration rate (mm/hr)**	
	Bare soil	Vegetated soil
Clay	0–5	5–10
Clay loam	5–10	10–20
Loam	10–15	20–30
Sandy loam	15–20	30–40
Sand	20–25	40–50

Soil pH

The effect of soil pH on fertility is related to the availability of nutrient elements over the pH range. The pH range that best suits soil fertility is between 6 and 7 for most plants. While some plants have adapted to grow in more acid soils or very alkaline soils, most plants grown on Australian farms prefer the middle pH(w) range 6.0–7.0 (Figure 26).

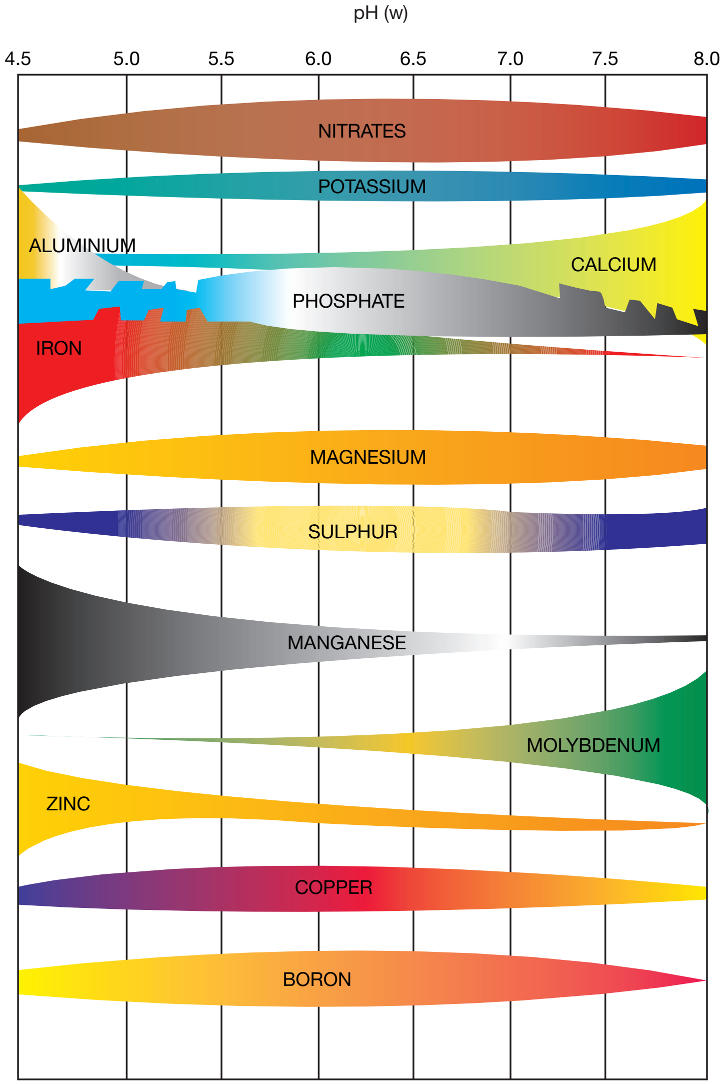


Figure 26 Nutrient availability over the pH(w) range found in most soils. (*Soil Sense* M-03)

Regular soil testing is an essential tool for understanding the nutrient status of farm soil.

How do I improve soil fertility on my farm?

There are a number of management practices that help improve and maintain soil fertility.

Keep the pH in the ideal range

On soils that are normally acid, keep the pH in the ideal range of between 6 and 7 by regular liming. In cropping systems pH(w) can fall to 5.5 before crops are affected greatly, but at this level the soil is not at its optimum. On very alkaline soils such as the Darling Downs region of Queensland, and the Mallee regions of Victoria and South Australia, it is not economically viable to try to acidify these soils and choosing plant species adapted to this pH range is the best option.

Regular soil testing

Regular soil testing to monitor pH and nutrient changes allows timely and appropriate action to be taken to correct any nutrient problems that may arise. Having the soil pH near neutral and the range of soil nutrients in adequate supply will encourage soil macro- and micro-organisms and plant growth.

Encouraging soil macro- and micro-organisms

Encouraging soil macro- and micro-organisms is an excellent way to maintain or improve soil fertility. The soil organisms prefer conditions that plants prefer, so by making conditions suitable for plants, the organisms are also encouraged.

Ideal conditions are: pH(w) in the 6 to 7 range; good soil structure with plenty of air voids present; adequate soil moisture present; adequate soil nutrients present and in balance.

Direct drilling and stubble retention

In cropping systems, direct drilling of crops and stubble retention will help maintain soil structure and encourage the soil organisms. This in turn will produce better crops, and help keep the farm sustainable.

Nutrient budgeting

Use the management technique of nutrient budgeting to monitor nutrient movements off the farm in produce, and back onto the farm in fertilisers. This technique is a very useful tool to help maintain soil fertility by maintaining adequate nutrient levels for subsequent crops.

Note. Nutrients applied as fertilisers should always be based on soil tests, and not nutrient budgeting alone.

Perennial pastures

In grazing enterprises, the use of perennial species in pastures, in preference to annual species, helps build soil structure. Managing these pastures by rotational grazing, and minimising stock pressure on the soil when it is very wet, will also help build and maintain soil structure.

> *A fertile soil is a living entity in itself, and the six factors listed above affecting soil fertility should be optimised in a balanced way for each class of soil.*
>
> *Fertility can be enhanced by sound management practices or destroyed by poor management.*

19

When to apply fertilisers to plants

Why is timing important?

A significant amount of fertiliser applied to crops and pastures is lost through:

- leaching down into the subsoil
- surface runoff into drains
- removal by wind as dust
- chemical changes in the soil, so it is unavailable to plants.

This fertiliser is therefore unavailable to plants and represents a farm cost that gives no return at all. In fact, it can increase the rate of soil acidification on the farm and cause environmental damage to streams and rivers.

Getting the best return for dollars spent on fertilisers

Obtaining the best return for dollars spent on fertilisers is achieved by working through the following steps:

- Take soil samples for each soil type and have them laboratory tested.
- From the test results assess the soil pH and adjust it if necessary. If the soil is acid, adding lime at the rate of 1 tonne per hectare will raise soil pH about 0.5 of a pH unit in a poorly buffered soil, and less in a well-buffered soil. Aim for a pH range of 6.0–6.5.

- From the soil test, work out which nutrients are needed to raise levels in the soil to an acceptable range for the crop or pasture in question.
- Apply the fertiliser according to the plants' needs, and to best effect by correct timing and using the most appropriate application method. For example, phosphorus can be rapidly tied up in the soil so ideally it should be applied when the plants need it most and are able to access it. This may mean split applications in an ideal situation. Potassium is readily leached, and if applied at heavy rates in one application, plants will take up more than they really need, and any excess may be lost by leaching.
- Remember, the nutrient present in the soil in the lowest amount relative to plant needs will limit plant growth. If this is the case, money spent on other fertilisers will be wasted as the plants are unable to make full use of them. To maximise the benefit of applied fertilisers, some fertilisers may be best applied in split applications. This can be achieved by using foliar fertilisers, which are sprayed directly onto the plants leaves and are rapidly absorbed. As there are no soil losses with this method of application, less fertiliser is needed. Alternatively, granular fertilisers can be applied in split applications, but wastage must be expected, as losses may occur before the fertiliser is absorbed by the plant roots.

How to apply split applications

Foliar fertilisers

Boom spray onto short crops or pastures.
Apply with a mister to taller crops or pastures.
Apply by aircraft.
Apply to spray-irrigated crops in the irrigation water.

Granular fertilisers

Apply with a fertiliser spreader.
Apply by aircraft.

Timing of applications

The following tables list the best times to apply fertilisers.

Depending on farm resources, the timing of applications may involve compromising the ideal timing due to practical realities.

Recommended fertiliser application times for cereals

(Source: *Soil Sense* M-01)

Cereal crops			
Fertiliser	**Dryland, low rainfall**	**Dryland, high rainfall**	**Irrigated**
Nitrogen (soil low in N)	(1) Predrill urea or sow with N/P blends (2) Before first node, or if crop yellowing	(1) Predrill urea or sow with N/P blends (2) Before flowering or if crop yellowing	(1) At sowing with N/P blends (2) Up until flowering, or if crop yellowing
Nitrogen (soil high in N)	(1) No N needed (2) If crop yellowing apply as soon as possible	(1) No N needed (2) After first node, or if crop is waterlogged (3) Before flowering	Up until flowering, or if crop yellowing
Phosphorus	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node
Potassium	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node
Calcium (lime)	Prior to sowing	Prior to sowing	Prior to sowing
Trace elements	(1) At sowing (2) If deficiency signs appear	(1) At sowing (2) If deficiency signs appear	(1) At sowing (2) If deficiency signs appear

Recommended fertiliser application times for annual pastures

New annual pastures		
Fertiliser	**Dryland**	**Irrigated**
Nitrogen	No N needed if legumes are sown In grass pastures, apply N at first signs of yellowing	No N needed if legumes are sown In grass pastures, apply N at first signs of yellowing
Phosphorus	At sowing	At sowing
Potassium	Sow in bands, or top dress after sowing	Sow in bands, or top dress after sowing
Calcium (lime)	Prior to sowing	Prior to sowing
Trace elements	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils	(1) If deficiency signs occur (2) Molybdenum every five years on acid soils
Established annual pastures		
Fertiliser	Dryland	Irrigated
Nitrogen	No N needed	No N needed
Phosphorus	At autumn break	(1) At autumn break (2) Booster in late winter
Potassium	(1) Early autumn (2) Late winter	(1) Early autumn (2) Late winter
Calcium (lime)	Every 8–10 years (soil test first)	Every 8–10 years (soil test first)
Trace elements	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils

Recommended fertiliser application times for perennial pastures

New perennial pastures		
Fertiliser	**Dryland**	**Irrigated**
Nitrogen	(1) No N required if legumes sown (2) Late autumn	(1) No N required if legumes sown (2) Late autumn
Phosphorus	At sowing	(1) At sowing (2) Late winter
Potassium	Band application before or after sowing	Band application before or after sowing
Calcium (lime)	Prior to sowing	Prior to sowing
Trace elements	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils
Established perennial pastures		
Fertiliser	**Dryland**	**Irrigated**
Nitrogen	(1) No N required if legumes sown (2) Late autumn	(1) No N required if legumes sown (2) Late autumn
Phosphorus	At autumn break	(1) At autumn break (2) Late winter
Potassium	(1) At autumn break (2) Late winter	(1) At autumn break (2) Late winter
Calcium (lime)	Every 8–10 years (soil test first)	Every 8–10 years (soil test first)
Trace elements	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils	(1) If deficiency signs appear (2) Molybdenum every five years on acid soils

20

Soil erosion

Soil erosion is a natural process, and much of the earth's landscape is formed from the action of wind and water eroding mountains and depositing the residue in valleys, creating more or less level plains. This oversimplified statement, however, does espouse the principle involved in erosion, which is that by the application of energy provided by wind and flowing water and the effect of gravity, material is moved to a lower state of kinetic energy and deposited at rest, at least for the time being. This process is never really completed, and with the effect of tectonic plate movements constantly adjusting slopes, wind and water will always try to move material from a higher to a lower level. The intervention of people into this natural system can, and does, lead to usually localised soil erosion that may be quite severe, causing high economic cost to the community and much inconvenience.

Erosion by water, or fluvial erosion

Water is very effective at eroding soil if the conditions are right, and names have been given to the different effects resulting from the erosion.

(a) Sheet erosion (Figure 27 on p. 109)

This occurs when significant areas of the soil surface have been removed and washed down slope. This is very damaging because the most fertile part of the soil has been removed, leaving an area without plant cover that will shed nearly all of any future rain events leading to more erosion down slope. It is also difficult and expensive to revegetate as part of the rehabilitation process.

(b) Rill erosion (Figure 28 on p. 110)

Rill erosion generally occurs on areas of cultivated ground after a heavy rain event. It takes the form of numerous relatively small, narrow rills all running down the slope eroded to the depth of cultivation or a little more. Significant volumes of topsoil can be removed and deposited further down the slope where it may be intercepted and held by vegetation, or where the slope decreases and the water loses its energy and the soil is deposited.

(c) Gully erosion (Figure 29 on p. 111)

This occurs where water runs off slopes and is concentrated in drainage lines. Gullies start at the lower end of the drainage line and work their way up the slope over time. A number of side gullies can form and join into the main gully causing extensive damage to the landscape. Gullies may be from only a few metres deep to a huge size such as the Grand Canyon in America. Soil may be deposited in fan formation at the end of the gully, or be washed into streams or rivers causing turbidity in the water.

(d) Tunnel erosion (Figure 30 on p. 112)

When the topsoil is relatively pervious and the subsoil is dispersive (sugary) as in a sodic soil, water may soak into the soil profile and wash channels of subsoil from under the topsoil, forming tunnels. The topsoil may later collapse, forming a gully. The displaced subsoil is typically deposited as a fan where the water comes to the surface.

(e) Stream bank erosion (Figure 31 on p. 113)

When stream and river banks become denuded of vegetative cover, they offer little resistance to the erosive force of water caused by flood flows or even the wave action caused by speed-boats. Floods can significantly change the course of a stream or river by bypassing bends or washing new channels. High vertical banks on the outside of a bend are particularly prone to erosion, with the soil collapsing into the river and being washed downstream. This soil may be deposited as sandbanks on the inside of bends, or deposited many kilometres away where the slope decreases and the water in the river slows down.

(f) Landslips (Figure 32 on p. 114)

These occur on steep slopes with little vegetative cover to stabilise the soil. After prolonged periods of rain when the soil is fully saturated, gravity can cause areas of soil to slump and slide downhill where it is deposited as a mound.

Erosion by wind or Aeolian erosion

In the right circumstances, wind can shift huge amounts of soil, sometimes large distances, and may even deposit it in other countries across oceans. Wind blown soil may end up as dunes, ridges or as flat plains with deep topsoils such as the loess plains of China.

Sheet erosion (Figure 33 on p. 114)

As with water erosion, wind may remove large areas of topsoil, leaving infertile subsoils exposed on the surface. Areas of cultivated light sandy soils are especially at risk, as are fine textured heavier soils. Bare soil surfaces caused by over grazing with stock with little or no vegetative cover are also at serious risk of wind erosion. Soil may be removed relatively short distances and be deposited as drifts against fence or tree lines, or, Victorian Mallee soil has been found as far away as in glaciers in New Zealand. Even now, it is not uncommon to find snow in the Australian Alps stained pink or brown by dust blown in on the wind.

Past land management practices led to severe wind erosion, and dense dust storms were not uncommon, depositing soil many kilometres from their source.

Soil deposition (Figure 34 on p. 114)

High velocity wind can pick up soil particles and keep them airborne until the wind velocity decreases and the soil is deposited back to earth, usually as a fine dust layer.

Larger soil particles may also be moved across the ground surface by a process called ‘saltation’, and again the soil will stop moving either when it comes against an obstruction, or when the wind velocity drops.

Each individual wind event may not necessarily move soil large distances, but left unchecked over decades or centuries, wind can move huge amounts of soil very large distances. For example, the sand in the dunes that are found in the Sahara desert originated in southern Africa, and was moved right up the west coast of Africa to the Sahara region.

In the past, soil movement in the Victorian Mallee could be severe enough to expose tree roots and cover fence lines in just one erosion event. At such times, visibility in the dust cloud was reduced to a metre or less.

Sandblasting

When wind-speeds reached high velocities, larger airborne soil particles could impact on plants and even structures, causing considerable damage. The outer protective layers of plants could be stripped away, destroying their ability to retain water, which could lead to the plant’s death.

Variables affecting water erosion

Water velocity

As the velocity and therefore the energy of moving water increases, its power to cause erosion increases markedly. This is especially so if the water is moving over bare unprotected ground or is channelled into drainage lines. Fast moving water can move large boulders and carry other large material such as trees, which can cause great damage to any structures (such as fences, buildings and bridges) the water plus debris impacts upon.

Water depth

As the depth of water increases, so does its ability to move soil particles, as it can cut into harder ground than shallow water and move larger objects such as stones, boulders and so on.

Distance

If water is able to travel long distances down even a gentle slope, in a heavy rain event the volume of moving water especially over the lower reaches of the slope can be very considerable. In this situation severe sheet and/or rill erosion can occur in a very short space of time.

Soil type

Light sandy soils are more prone to erosion than heavier soils that have better developed crumb structure and are better able to resist the erosive power of the water. Regardless of soil type, a soil with good plant cover will be better able to resist erosion, but even so, the lighter soil is still more at risk.

The other variable with soil type is the effect of soil chemistry, and a highly dispersive soil such as a sodic soil has a high erosion risk compared to a chemically well-balanced soil.

The structure of the soil is also important, and a soil with well-balanced chemistry can also have good physical properties such as well-developed crumb structure, good aggregation, good porosity and low bulk density. Such a soil will allow rapid water infiltration, support strong healthy plant growth and soil microbiology, and the organic acids and polysaccharides present bind the soil particles strongly together. Another soil problem is that of nonwetting sands, or hydrophobic soils. In this case, water is unable to penetrate into the soil because of waxy coatings formed on the soil particles by fungi. This repels water, causing it to run off the soil surface causing erosion.

Ground cover

Bare soil is much more prone to erosion than soil with even moderate amounts of vegetative cover. This cover does not have to be living plants, but dry crop or pasture stubble or various forms of mulch can also effectively protect soil from erosion. The important issue is that the plant matter or mulch absorbs the energy from the raindrops, and prevents soil particles being loosened and displaced. In areas where earthworms are very active, their castings on the soil surface can also help protect the underlying soil. Bare soil may be the result of management practices, or could be the result of wildfires, which may almost completely remove vegetative cover over large areas, often in steep, highly erodable country. The quality of ground cover may also be limited by the fertility of the soil, and if fertility is low, then it may only support sparse vegetation.

Soil management

The quality of land management can have a large effect on how prone the soil is to erosion. As previously discussed, maintaining at least some vegetative cover on soil is very helpful. Avoiding soil compaction from heavy stocking rates on wet paddocks, or excessive trafficking by vehicles or machinery, will help reduce water runoff and hence erosion. Avoiding long periods of bare cultivated ground when cropping by replacing fallowing prior to sowing crops with the direct drilling or stubble mulching methods, will greatly reduce the risk of soil erosion.

Variables affecting wind erosion

Wind speed

As with water, the higher the wind speed, the more energy it has to shift soil, and again large areas of loose soil are especially at risk if they have no protective plant cover.

Area of unprotected soil

The greater the exposed area, the more prone it is to erosion by wind. This is because there is nothing to slow the wind down or dissipate its energy by diverting it from its path. There is nothing to prevent it from moving soil particles that can then gain energy and themselves impact on more soil particles, causing mass soil movement. The wind can then pick up and carry this moving soil until it loses velocity and the soil is deposited. There are two aspects to this: (1) soil movement along the surface, and (2) soil movement through the air. It is the larger and heavier particles that move along the surface, and the lighter particles that move through the air.

Soil type

The same remarks that apply to soil erosion by water apply to soil erosion by wind. The lighter soils are most at risk, and the heavier and better structured soils are least at risk. It should be remembered that any soil if cultivated too fine is prone to erosion by wind.

Ground cover

As for water erosion of soil, ground cover protection is very important in preventing or at least minimising wind erosion. This may apply on a small scale by maintaining pasture or crop cover on the soil, planting windbreaks to protect relatively small areas or very large area grid planting of trees to lift prevailing winds up above ground level, creating microclimate effects between the tree grids.

Figure 12 The effect of potassium on pasture composition – enhanced clover production. (*Soil Sense* C-06)

Figure 13 Dense magnesium rich clay. (*Soil Sense* C-09)

Figure 14 (Top) Lime deficiency in lupins. Healthy leaf is on the right. (Bottom) Manganese deficiency in canola. (*Soil Sense* C-08)

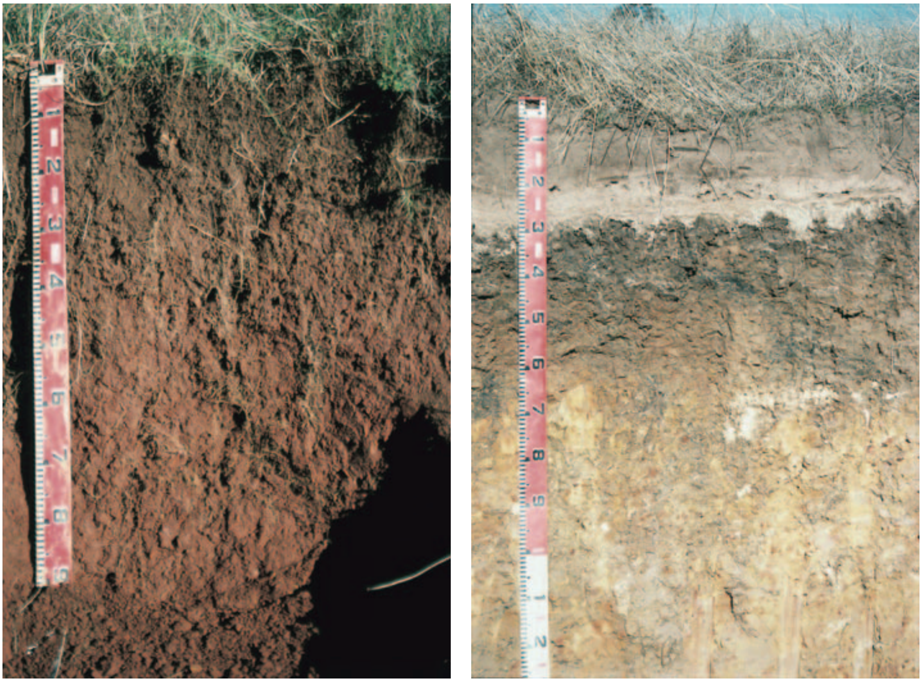


Figure 16 The effect of cations on soil profiles. (Left) Friable, well-structured clay. (Right) Dispersive sodium clay. (*Soil Sense* C-09)

Figure 17 White clover with adequate sulphur (left) and sulphur deficient (right). (*Soil Sense* C-04)

Figure 18 Agroforestry on soil with high aluminium toxicity. (*Soil Sense* C-07)

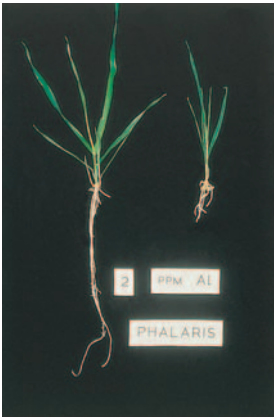


Figure 20 Effect of aluminium on phalaris. The plant on the left has zero aluminium, whereas the plant on the right has 2 ppm of aluminium. (*Soil Sense* C-07)

Figure 21 Plants vary in tolerance to soil acidity. Barley is highly susceptible to aluminium (left), whereas lupins are very tolerant (right). (*Soil Sense* C-07)

Figure 27 Sheet erosion.
(Photo by Lynn Betts, USDA Natural Resources Conservation Service)

Figure 28 Rill erosion. (Top) Soil is deposited in the delta from rill erosion (Photo: Bruce Carey). (Bottom) Rill erosion on the roadside (Photo: Michelle Batko).

Figure 29 Gully erosion. Top photograph shows the head of the gully. (Photo: Michelle Batko)

Figure 30 Tunnel erosion in a pasture (top) and through a dam bank (bottom). (Photo: Michelle Batko)

Figure 31 Stream bank erosion. Actively eroding stream bank (top), and stream bank trees undermined, collapsing into the stream (bottom). (Photos: Bruce Carey (top), Michelle Batko (bottom))

Figure 32 Landslip erosion on steep slope. (Photo: Michelle Batko)

Figure 33 Light soils are especially prone to wind erosion when cultivated. (Photo: Bruce Carey)

Figure 34 Soil deposition. Wind-blown soil clogs a road ditch. (Photo courtesy of USDA Natural Resources Conservation Service)

Figure 35 Strip cropping for erosion control. (*Soil Sense* P-01)

Figure 36 Compact sandy loam before (left) and after (right) breaking into coarse clods. Note how few roots are visible. (Photo courtesy of Scottish Agricultural College (SAC))

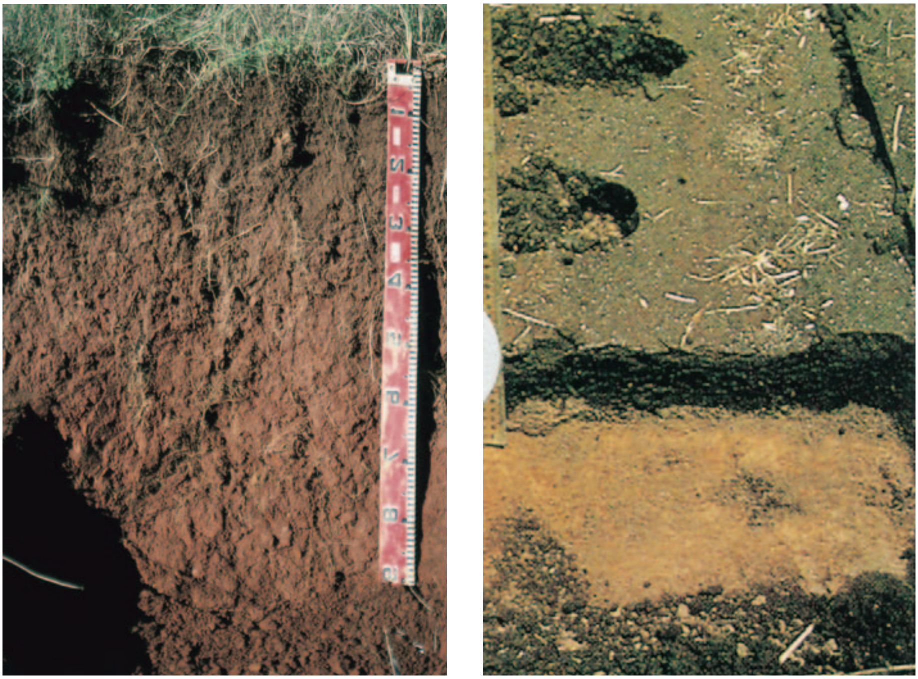


Figure 37 Left: A soil with good crumb structure and high organic matter content. Right: A degraded soil with poor structure in the cultivated layer, and compaction below the cultivated layer. (*Soil Sense* P-02).

Figure 38 Waterlogging in compacted soil. (*Soil Sense* P-02)

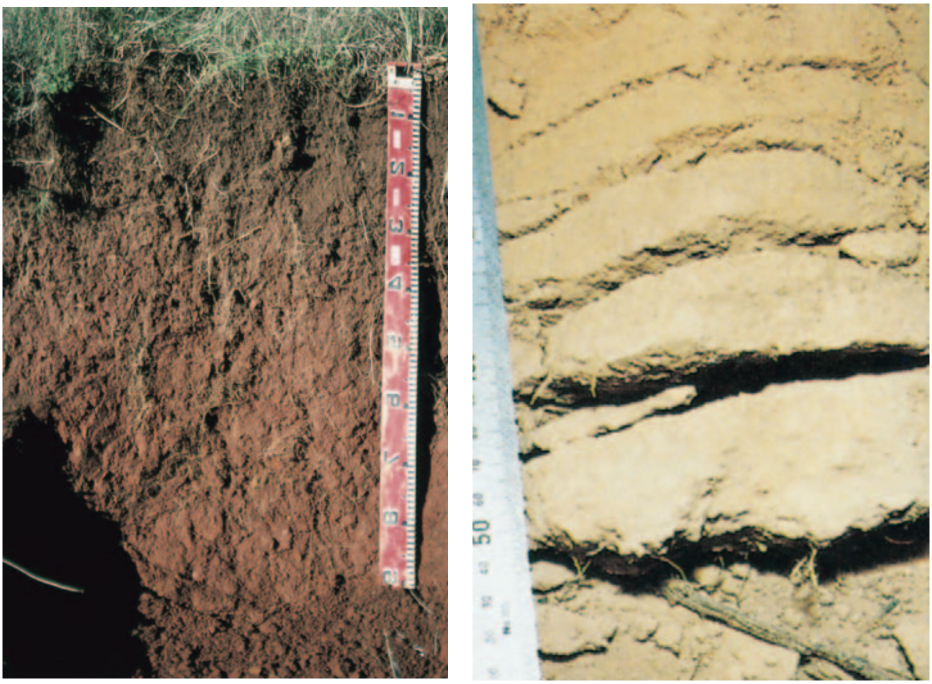


Figure 39 Left: A well-structured soil. Right: Hardpan layers in degraded soil. (*Soil Sense* P-03)

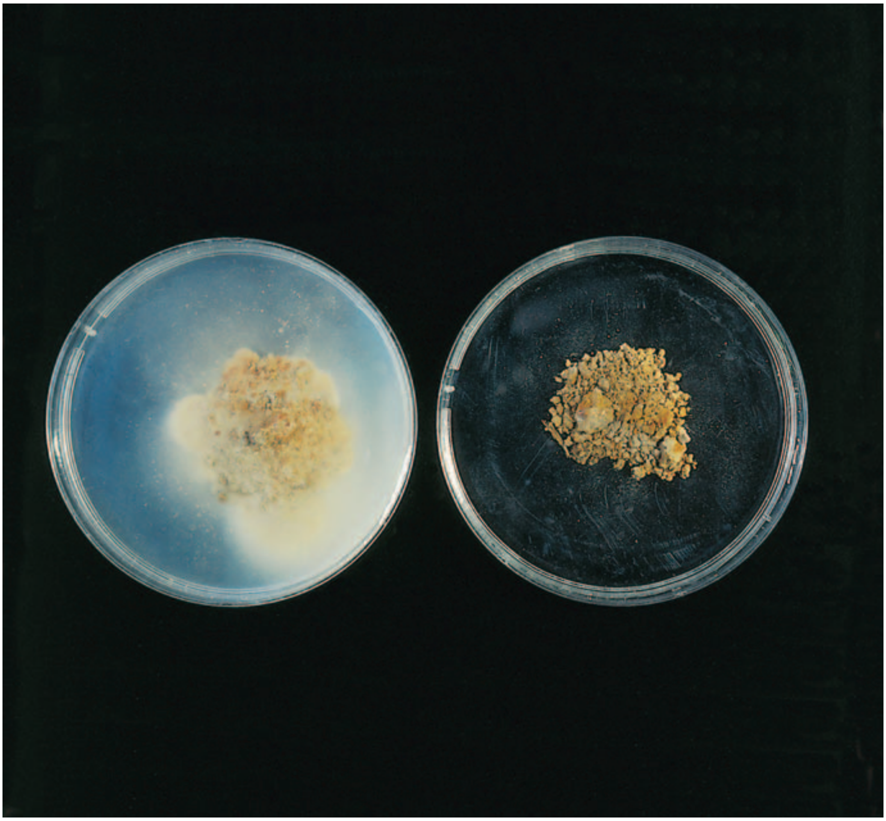


Figure 40 Cloudiness shows dispersion (left dish) compared with slaking or crumbling of the soil lump (right dish). (*Soil Sense* P-03)

Figure 41 Soil crusting will often inhibit seedling emergence. (*Soil Sense* P-03)

Figure 42 (a) Hammer the infiltration ring into the ground, (b) Fill the ring until it is overflowing, (c) Measuring the rate of water drop in the ring. (*Soil Sense* P-03)

21

Repairing and preventing soil erosion

Control options available

Ground cover

A relatively simple technique for preventing soil erosion by water and wind is to maintain a good vegetative ground cover. Dense pasture cover is ideal, but any vegetation that intercepts raindrops and dissipates their energy before they hit the soil is suitable. Vegetation also helps catch and hold any soil particles that are being moved by water runoff or wind. Re-establishing vegetative cover on areas where erosion has begun will help the area stabilise and heal the soil scarring, allowing topsoil to reform and increase the ability of the area to support healthy plant populations.

Cultivating or ripping the affected area on the contour to loosen the soil and hold water where it falls, which helps it soak into the soil and not run off the area taking soil with it, sowing it to a heavy rate of crop or pasture, and providing plenty of nutrients for the plants' needs will help to repair the area as soon as possible. It may also be advantageous to plant windbreaks to help protect the area from strong prevailing winds.

Water management works

On sloping ground, controlling water flow by building contour banks at regular intervals down the slope will help rainfall to soak into the soil and limit the distance down the slope that water can run without being intercepted.

A variation of this is the use of graded banks built on a slight slope (say 0.5%) that will move water safely in the direction of the fall. This water can be run onto a grassed waterway or constructed head-works to safely take it to a lower level in the landscape or to collect it in a dam. A further water management tool that has proved very successful in practice is the keyline farming system as developed by P.A. Yeomans.

Cropping techniques

A time of high risk of soil erosion is when soil has been conventionally fallowed in preparation for sowing, which leaves the soil surface bare, loose and broken into fine particles.

From a soil erosion point of view, the newer planting techniques of minimum till planting and direct drilling are much preferred options. In these cases, the soil surface remains intact and often with plant cover right up to the point of sowing the new crop. This means the opportunity for erosion to occur is almost negligible.

A modification on these techniques is stubble mulching, where the new crop is sown directly into the stubble of the preceding crop. Again, this means there is no time in the cropping phase where the soil is not protected by plant cover.

Another technique used, especially when cropping large areas of sloping ground, is strip cropping, where contour or graded banks are built at regular intervals down the slope, and every second bay is cropped with pasture or fallowed in between the cropped bays. This is especially useful in areas of summer cropping or when crops are rotated a number of times before a pasture phase (Figure 35 on p. 115).

Types of crop

Different types of crop vary in their effectiveness in helping to prevent soil erosion. Pastures, cereal crops, sorghums, millets and brassicas are effective at protecting soil but other crops such as sunflower, safflower and chick-peas are far less effective due to the distance between plants. The different cultural requirements of the various crops can also mean that the soil may be unprotected at a time of year that can be prone to heavy storms or consistent high winds, thus increasing the risk of an erosion event.

Trees in the landscape

Past practices of extensive land clearing led to extensive soil loss due to erosion, and these practices are now largely discontinued. Instead, the value of trees, shrubs and groundcover plants in the landscape has been realised for many reasons, including their effect in reducing erosion.

In terms of controlling water erosion, trees find particular use in stabilising river and stream banks and lowering water-tables. This helps prevent dryland salinity developing that changes soil chemistry, making soil more dispersible and more easily eroded. Windbreaks aid greatly in reducing wind erosion if they are sited carefully and at the same time they provide protection for crops and stock.

Grazing pressure

In normal years of average rainfall it is normal practice for farmers to maintain some vegetative cover on paddocks to help maintain the soil and pasture health. In times of drought, and especially if the drought lasts over a number of years, soil can become very bare indeed, leaving it highly vulnerable to erosion when the rains do come, or to erosion by wind. One answer to this is to set aside one or more small areas for hand feeding stock on, which takes the pressure off most of the farm. In an extended drought even this may not be possible due to over extended resources, leaving no other option than de-stocking the farm. Managing pastures by rotational grazing or cell grazing techniques may also result in better ground cover than set stocking.

Specific methods used to repair erosion

Sheet erosion. Contour rip or cultivate the area and sow it to a pasture or crop at a high sowing rate. Possibly use diversion banks and grassed waterways to safely take water from the eroded area to a lower level in the landscape. Possibly need to plant windbreaks for wind control.

Rill erosion. Contour rip or cultivate the area and sow it to a pasture or crop at a high sowing rate. Possibly use diversion banks and grassed waterways to safely take water from the eroded area to a lower level in the landscape.

Gully erosion. Install gully head-works to carry water to the floor of the gully. Divert water from the head and sides of the gully using diversion banks. Fence the gully to exclude stock and revegetate top, sides and floor of the gully. Build groynes in the floor of the gully to trap silt to help fill it over time. On small gullies, batter the banks using earthmoving machinery, and sow to pasture, trees and shrubs. Species such as casuarinas and some acacias with multiple fibrous roots are preferred plant options.

Tunnel erosion. Collapse the tunnel using earthmoving equipment and batter the edges. Install diversion banks to divert water from the affected area. With severe tunnel erosion, it may be necessary to use head-works to prevent gully erosion developing once the tunnels are collapsed by machinery. Fence the area off from stock and revegetate with deep-rooted species. Gypsum may be needed if the area is sodic.

Stream erosion. Protect eroding banks using groynes built out from the bank into the water to reduce water speed next to the bank and help trap silt. Batter banks and plant trees with strong fibrous roots, such as casuarinas, to hold the soil in place. In fast-flowing streams or rivers, place rock against the bank to absorb the energy of the flowing water.

Sand drifts. In coastal sand dunes subject to constant strong winds, the only way to protect them is to cover them with a thick mulch (such as branches of shrubs) and revegetate the area with grasses and/or shrubs and/or trees. The area needs to be regularly checked for 'blowouts' that should be covered and replanted as soon as possible. Large areas of drifting sand such as large dunes or long ridges are virtually unstoppable unless they can be stabilised with vegetative cover.

Landslips. Once a landslip has happened, it may become relatively stable, or may continue to slip on steep country in high rainfall areas. Treatment is usually achieved by establishing deep-rooted vegetative cover in the slip itself and in adjacent areas. If the problem is caused by water travelling down aquifers, then extensive revegetation may be required. It may also be helpful to put in interception banks on a slight grade (0.5%) to divert water from above the slip area.

22

Soil compaction

What is soil compaction?

Soil compaction can occur when the crumbly structured nature of a virgin soil in good condition is collapsed by stock or machinery traffic, or by too harsh or too many cultivations. Prolonged rainfall can also lead to compaction of dispersive soils. Compaction can occur in surface or sub surface layers, or both (Figure 36 on p. 116).

> *Plant roots find it difficult or impossible to penetrate compacted layers, leading to poorer crops and pastures.*

What does soil compaction do?

Compacted soil is less permeable to water, leading to reduced absorption of rain and irrigation water. Because pore spaces between the soil particles are smaller and fewer in number, this causes more rainfall to run off and be lost from the farm, thus reducing potential yields.

Plant roots may find it difficult or impossible to penetrate compacted layers, leading to poorer crops and pastures with less drought tolerance. The soil has fewer and smaller spaces between soil particles, reducing plant root respiration and desirable microbiological activity. This leads to poorer plant growth and an increase in plant diseases.

Compacted soils are more difficult to cultivate (causing higher fuel costs), take more time to work, and increase wear on soil cultivation machinery.

Compacted soils set harder, which means they are workable for a shorter time than uncompacted soils.

What causes soil compaction?

There are a number of causes of soil compaction:

Excessive mechanical cultivation, leading to damaged soil structure.
Trafficking by machinery and stock – especially when soil is wet.
Loss of organic matter from the soil – especially the humus that binds soil particles into a crumb structure.
Heavy rainfall on, or irrigation of, cultivated soils, or soils low in organic matter.
Some soil chemical reactions can cause cemented layers to form, for example silcrete, ferrocrete or calcrete.
The chemical make-up of the soil, usually comprising too much sodium or not enough calcium.

How to prevent compaction

Avoid unnecessary stock or machinery traffic on wet soil, especially if plant cover is poor.
Direct drill crops, or at least use minimum till methods of cropping.
Maintain good pasture cover as much as the farming system will allow. Pastures should contain a high component of deep-rooted species such as grasses, and preferably some perennials.
Avoid excessive trampling of wet soils by stock, especially sheep and cattle as their feet exert very high pressures on the soil. This applies particularly to heavy soils.
Avoid use of implements such as rotary hoes, disc ploughs and disc cultivators. These implements cause more damage to soil structure than tyned implements and rapidly break down soil structure.

What are the effects of soil compaction?

Water penetration into the soil is reduced, leading to less soil water stored and increased runoff, with increased erosion and loss of plant nutrients.
Pores between soil crumbs that contain air are smaller or collapsed. This leads to unfavourable conditions for plant roots and soil organisms.
Reduced penetration to depth by plant roots, thus limiting nutrient uptake.

Increased moisture stress on plants and soil organisms in dry or drought conditions.

Increased waterlogging of topsoil during wet seasons, leading to poor plant growth.

Waterlogged soils inhibit beneficial soil microbes and favour disease organisms, increasing the risk of crop diseases.

Less crop or pasture growth leads to lower net farm income.

Poorer stock health, also leading to poorer net farm income.

Waterlogging

Water ponding on the soil surface after relatively light rain, or remaining ponded for several hours after rain, can indicate soil structural decline (Figure 38 on p. 117).

How to ameliorate compacted soils

Deep rip under favourable soil moisture conditions with an implement such as a paraplough or a winged ripper. The soil should be evenly moist, neither too wet, nor too dry for this treatment. (Deep ripping may not be effective on dispersive soils.)

Follow up deep ripping by planting deep-rooted plants, then minimise traffic by stock and machinery. The use of controlled traffic methods of sowing crops (tramlining) using GPS guidance systems will limit compaction by machinery.

Use deep-rooted perennials in pasture mixes.

Applications of gypsum may help if the soil has high clay content only if the clay is sodic or contains high levels of magnesium.

What does it cost to repair compacted soils (2006)?

Deep ripping

Cost per hectare will vary depending on soil conditions, depth of ripping and equipment used. Contract rates are more or less locally determined, but will be of the order of $150/ha. Farm owned machinery may be available, and therefore making it cheaper per hectare, but contractors often have heavier machinery that may more easily be capable of doing a high quality job.

Planting pastures

Cost per hectare to sow perennial pasture will depend on the seed mix and fertiliser used but will be in the range of $250 to $350/ha done by the farmer.

Applying gypsum

The cost of gypsum varies depending on its source and the purity of the product. A working figure is around $50 per tonne ex works. Transport costs will add significantly to the cost at the farm gate, and will vary with transport distance. Contract spreading costs will be around $10 to $15 per tonne.

The total cost of treatment is quite high, but benefits of increased productivity will last a number of seasons.

Note. It is strongly advisable to obtain a chemical analysis of the gypsum to be used prior to application to check that it does not contain excessive sodium (Na), which could negate the major benefit of applying the gypsum.

What happens if compacted soils are not repaired?

A loss of potential farm productivity can be expected, and if soil compaction is severe, soil loss due to erosion and hence a decline in the farm's main asset, the soil, is inevitable.

23

Soil structural decline

What is soil structure?

Soil in good physical condition should have a soft porous, crumbly structure, where small soil particles have formed into aggregates. These aggregates are numbers of soil particles glued together by clay and organic compounds such as humus.

The formation of soil aggregates leaves spaces between them that will contain water and air (oxygen), and provide easy access for plant roots.

Not all soils have this type of structure in the native environment. For example, sandy soils with low levels of organic matter are fragile, are easily damaged and have poor water holding capacity. At the other extreme, heavy blocky clay soils composed of very fine particles are very dense, with small pore spaces and hold water tightly.

An ideal soil is one with well-formed aggregates in a loose-packed arrangement that is not easily broken down by water, stock or machinery.

Assessing damage to soil

Loss of surface structure

A soil with a damaged surface structure will be powdery and cement-like when dry, and muddy and pond water when wet.

Plant growth will be restricted and wet soil will probably be waterlogged.

The soil is dense and hard to penetrate with hand tools or machinery when dry, and boggy when wet. Sodic soils can also develop strong surface crusting.

Hardpans

These are hard layers, usually at the depth of maximum cultivation, but can occur almost at the surface, or even deeper in the soil profile. They reduce water, air and plant roots penetrating through them, and can cause serious loss of yield and waterlogging of the surface soil by inhibiting drainage.

The occurrence of hardpans can be determined by pushing a 6 mm diameter steel rod up to one metre in length into the soil when it is moist, and noting increases in effort needed to push the rod to depth. If a hardpan is present, it will be difficult to push the rod through this layer. This rod can be attached to a device that measures force to make an instrument known as a penetrometer.

Loss of subsoil structure

If the subsoil has become compacted, water penetration down the profile will be poor, and will usually show up as surface waterlogging, or excessive water runoff after rain.

Plant roots will have great difficulty penetrating to depth, and will have less drought resistance and poorer growth.

To check subsoil structure, it will be necessary to dig a hole, preferably a metre or more deep, and carefully inspect the face of the soil profile. Dispersion can be seen as very dense sticky clay, often due to too much sodium compared to calcium. Clays high in magnesium are very hard and dense, with a large columnar structure.

The extent to which water and plant roots are able to penetrate soil profiles can also be determined by looking for roots at depth. Roots may be seen to reach a point where they turn and go sideways instead of continuing down the soil profile if they hit a hardpan. This effect may also be due to acidity, sodicity or salinity. (See Figure 39 on p. 118.)

Detecting sodic soil

Too much sodium in the subsoil will cause the clay particles to disperse and slump together in a dense mass.

This can be checked by taking two or three pea-sized samples of the clay and placing them in a shallow container of rainwater. If the clay is sodic, a cloudy appearance will develop in the water around the clay. The quicker and more completely this happens the more sodic the soil.

Note. Dispersion should not be mistaken for slaking, which occurs when the clay sample crumbles down to a slurry with little or no cloudiness in the water.

The same test can be done by taking a moist sample of the soil and working it between the fingers for a while then putting a few pellets of this reworked soil in the water. If it disperses after this treatment it is an indication that the soil is fragile, and can be easily damaged by cultivation, especially when too wet (Figure 40 on p. 119).

Crusting

Cultivated soil with reasonably high clay content can form surface crusts after rain, which may inhibit seedling emergence. This crusting is easily observed.

Crusting is usually caused by too much cultivation and/or too low an organic matter content of the soil. The remedy is to return the soil to a pasture phase, or increase organic matter content by stubble retention, minimum till cropping or green manuring. Sodic soils are also prone to crusting (Figure 41 on p. 119).

Responding to soil structural decline

Structurally damaged soils probably mean that farming practice needs to be critically assessed to find the cause of the problem that should then be addressed.

This may mean shifting from conventional cultivation to minimum till or direct drilling techniques in cropping, and careful stock management in grazing enterprises. If stock can be kept off wet paddocks when they are saturated, or at least rotationally grazed with a system like one week on, and seven weeks off in wet weather, the soil will have a chance to self repair.

If too much sodium is the problem it may be possible to make the soil more friable and reduce surface crusting by using top dressings of gypsum periodically. This should be combined with growing deep-rooted crops or pastures, so roots can hold the soil open.

How does soil structure decline?

Soil structure can be damaged over time in a number of ways.

By water

Rain falling on bare soil will impact hard enough to break soil aggregates into smaller particles, which are then easily removed by erosion, or compacted to form a dense soil that inhibits plant growth and water penetration.

By machinery

Wheels of all types of machinery can compress soil into compacted layers, which then resist water penetration and inhibit plant growth. This is more so when wet soil is trafficked.

Cultivating soil can also rapidly destroy soil structure especially if it is performed when the soil is too wet or too dry, or done too often. Some machines are more damaging to soil structure than others, with rotary hoes and disc ploughs being among the most severe.

By stock

The pressure of stock feet on wet soil can severely damage soil structure by causing compaction and pugging. This is especially so if plant growth is poor and not many roots are present to hold the soil together.

By salt

The sodium in salt will bind to clay particles and replace the calcium that helps hold the soil together. This causes the clay to disperse, and the detached clay particles then clog the pore spaces. This reduces the aeration and the permeability of the soil that restricts water movement and plant root growth. Salt in the soil reduces the ability of plants to take up water, and the sodium in the salt can be toxic to plants, depending on how concentrated it is in the soil.

Note. Irrigating sodic soils with slightly salty water can retain good soil structure, but crop production will be limited by sodium toxicity.

24

Water movement in soil

The study of water movement in soil is quite complicated, and soil scientists use a number of terms to describe different aspects of water movement.

From a farmer's viewpoint it is the effects of water movement that will determine land management issues. The important issues of water movement in the soil are how much water is available to plants, the rate of nutrient leaching and the extent of waterlogging.

Infiltration

This term describes the movement of water from the soil surface into the ground. Water movement is greater when the soil surface has many open pores that water can enter, and less when surface pores are clogged by compaction or siltation, or in the case of nonwetting sands, by waxes repelling water.

Hydraulic conductivity

This term refers to how fast water is able to move through the soil. For example, water can move easily and rapidly through a light sandy soil, but can have great difficulty moving through dense clay, and cannot do so at anything like the same rate as the sandy soil.

How fast water will move in a soil depends on how wet the soil is, so hydraulic conductivity measurements are taken for dry soil being wet up, and for soil that is fully wet. The terms used are: hydraulic conductivity unsaturated or hydraulic conductivity saturated.

How is water movement measured?

The amount of water a soil can absorb is often tested in the field by pushing a metal or plastic ring into the soil to about 10 centimetres depth, taking care that the top of the ring is level. The ring is then filled with water, and the rate at which the water moves into the soil is measured over time using a clock and a ruler.

When water is being put inside the ring, it is necessary to prevent damage to the soil surface by pouring the water onto a flat hard material such as a piece of plastic, or a shovel blade, instead of directly onto the soil itself. The protective material is then removed. The diameter of the ring is not critical, but is usually of the order of 30 centimetres. The measurement is usually taken in millimetres, and the rate of water infiltration expressed in millimetres per hour. (See Figure 42 on p. 120.)

> *The amount of water a soil can hold will influence how much crop or pasture can be grown on that soil.*

Topsoil and subsoil differences

In a soil type with a deep porous topsoil (the A horizon), water will probably move downwards fairly quickly, unless there are hardpans present that would restrict the flow of water.

However, in a soil with a porous, light textured topsoil over a heavy clay subsoil (the B horizon), the water will move quite rapidly through the topsoil, and much slower through the subsoil below once the topsoil is saturated. In this case it may be a good idea to dig the topsoil away to the depth of the clay subsoil, and place the ring at this depth. This will give a more realistic idea of how well this soil will accept water, and will identify the likelihood of waterlogging occurring in the topsoil.

Dry or wet soil?

This test can be done in dry or wet soil, but the measurements obtained will be different. When testing a dry soil, the initial reading will probably be higher than readings repeated after the water from the first reading has soaked away. It is usual practice to repeat readings until results from subsequent readings are the same, and this can be quite time consuming.

Why do this test?

Recharge mapping in salinity work

If salinity is a problem in the area, then by doing infiltration tests at a number of sites along slopes and on hilltops, areas of high infiltration can be mapped. This gives important information to add to other data when planning remedial work. Usually areas that have a high infiltration rate are sown to plants that have a high water use, such as trees or deep-rooted perennial pastures. Figure 43 shows water movement in soil that has been cleared of tree cover.

To investigate a soil problem

If waterlogging is a problem, then the first step in dealing with it is to find the cause and evaluate how bad the problem is. It will be obvious when looking at a waterlogged crop the effect it is having and the area concerned, but it is not so obvious what is causing the problem.

The cause may be loss of soil structure from too much cultivation or over cropping, or hardpans from stock or machinery pressure on the soil.

It may also be due to chemical imbalances in the soil such as too much sodium. This causes the soil to slump when wet, which reduces water infiltration. The infiltration test will help show where in the soil profile water movement is restricted, which will help in planning remedial measures.

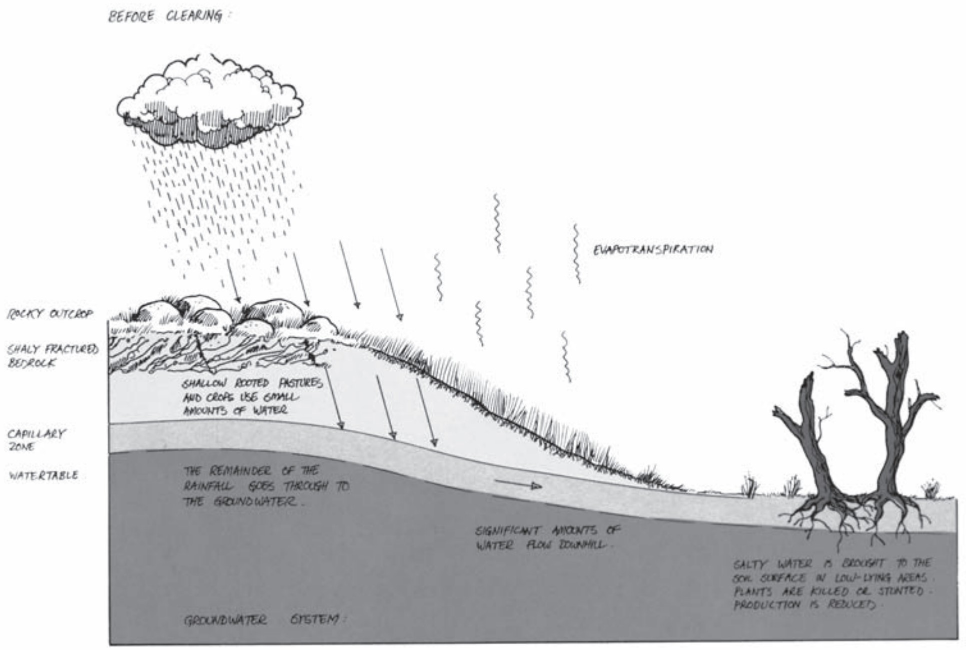


Figure 43 Changes in the hydrological cycle following the clearing of native vegetation. (*Soil Sense* P-04).

What are normal infiltration rates?

There are big differences in rates of water movement into different soils and subsoils, so normal rates will vary from one soil type to another. Table 21 shows typical infiltration rates for a range of soil types, and the comparative rainfall events that will soak into the soil without causing runoff or damage.

Table 21 Soil infiltration rates

(Source: *Soil Sense* P-04)

Description of infiltration rate and soil type	Infiltration rate mm per hour	Infiltration rate mm per day	Rainfall event that saturated soil can absorb	Effect on farmland
Very slow (clay)	>1.0	<24	Drizzle	Liable to waterlogging
Slow (clay-loam)	1–5	24–120	Light rain	Poor infiltration and runoff on slopes
Moderately slow (silty clay-loam)	5–20	120–480	Moderate rain	Poor infiltration and runoff with erosion risk
Moderate (silty loam)	20–60	480–1440	Heavy rain	Probable erosion on long or steep slopes or bare soil
Moderately rapid (loam)	60–125	1400–3000	Downpour	Erosion on long or steep slopes and bare soil
Rapid (sandy loam)	125–250	3000–6000	Violent rainfall	Moderate erosion on slopes, bare soil and drainage lines
Very rapid (sand)	>250	>6000	Cloudburst	Severe erosion on slopes, bare soil and drainage lines

Water storage in the soil

Light textured soils with fast infiltration rates wet rapidly, but may store insufficient water in the profile for use by plants. Nutrients leach below the root zone readily, thus lowering soil fertility.

On the other hand, soils with slow infiltration rates take longer to wet up, but hold the water tighter and longer. Not all the water in these soils is available to plants, as the soil can hold some water more strongly than the plant’s ability to remove it.

Responding to test results

Poor infiltration on normally good soils

A soil that used to drain well but now has waterlogging problems indicates a loss of crumb structure, or the formation of hardpans. These problems may be due to excessive cultivation, over cropping or compaction by stock. It may also be caused by problems higher up the slope draining more water onto the soil being considered.

If cropping, options may include:

Deep ripping to break up hardpans.
Changing to minimum till or direct drilling methods of sowing.
Deep ripping and sowing down to deep-rooted perennial pasture.
Avoiding trafficking the soil with machinery as much as possible, especially when the soil is very wet. Wide tyres with low inflation pressures significantly reduce soil compaction if machinery must be used on wet paddocks (Figure 44).

If livestock are contributing to the problem, options may include:

Try to have as few livestock as possible on high-risk paddocks when the soil is wet.
Practise rotational grazing so livestock are only on a paddock for say one week in seven. This gives the soil a chance to self repair.
Sow deep-rooted perennial pastures if the climate and soil allows.
Aerating the soil using a narrow tyned ripper to loosen the soil and break up hardpans as they develop may be warranted.
Use a management system that encourages high levels of organic matter and biological activity in the soil.

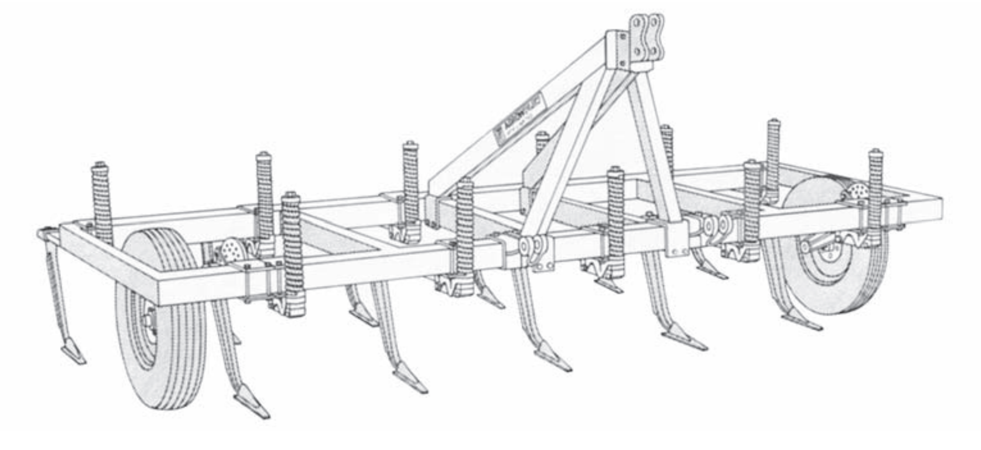


Figure 44 A machine suitable for breaking up shallow hardpans. (*Soil Sense* P-04)

If soil chemistry is the problem

Sodic soils (soils with too much sodium compared with calcium) can be treated with gypsum to address the nutrient imbalance. If the soil is highly sodic, high rates of gypsum addition (20 tonnes per hectare or more) may be needed. Gypsum treatments are not successful on all soils, so proper testing needs to be done before the decision to proceed with this treatment is taken.

25

Urbanisation in rural areas

The global situation

An area of great concern to agricultural planners is how to feed, clothe and shelter the ever-increasing world population, which is expected to double by the year 2020. The greatest concern is the area of quality agricultural land that is available, and the rate of degradation of land currently used for agricultural purposes.

The increasing economic pressure to increase production from land currently used for agriculture has led to a massive loss of soil fertility due to structural decline, acidification and the various forms of erosion. To restore these degraded soils is a massive task, which is probably beyond the scope of most farmers to undertake without high levels of financial support. At the same time, quality agricultural land is being lost to urbanisation at an alarming rate, which is having the effect of placing even more demand for increased production from the remaining agricultural land.

Globally, nearly all of the quality land is being utilised for agriculture, and the remaining undeveloped areas are generally not suitable for sustainable agricultural use, because of poor soil quality, unsuitable rainfall or other shortcomings of the land.

Certainly, quality land is a finite resource, which needs to be recognised as irreplaceable, and upon which the food and fibre for future generations depend.

The need for future planning

There is an exponentially increasing demand for food and fibre, based on global population increases. At the same time there is a continuing reduction in the availability of quality agricultural land with much of the land being lost to other uses, particularly urbanisation and infrastructure demands.

There is a need to rethink how land is utilised for the future, and this is especially so when it comes to urbanisation. There needs to be recognition that it will be necessary to plan land use carefully and to prioritise land use for particular purposes (such as industrial, rural and so on). It is no good having well-planned cities built on quality agricultural land if the inhabitants of the city are starving through lack of suitable land to grow food.

The answer to this problem is to plan to reserve quality land for agriculture, and urbanise lower quality land. Infrastructure support such as roads needs to be kept at minimum suitable levels to serve community needs, and the geographical locations of future urban areas needs to be carefully considered.

Local planning needs to identify the ‘green’ areas with good soil and water supplies, and designate them for the food and fibre needs of the community.

Urban areas should be located on the poorer soils and planned for efficiency of use of space, and with adequate, but minimum areas used for infrastructure support.

Future development needs to be very carefully planned to minimise the urban encroachment of quality land, which is better used for agriculture, or environmental needs such as forested areas to supply clean water and replenish atmospheric oxygen. These issues will become vitally important over the next few decades, and planning needs to start now. The right of governments and individuals to own, occupy and use land in future may be linked much more closely to the planet’s long-term survival than it is at present.

Infrastructure needs

There is a great deal of quality agricultural land used for infrastructure purposes, such as road and rail reserves, water supply dams and easements for power distribution. Certainly a proportion of this use is quite unavoidable, but if the costing of these works took account of the cost of loss of irreplaceable quality land, then the planning stage may allow rerouting to minimise these losses.

The cost of infrastructure would then take into account the cost of supporting a larger global population, and any extra capital costs would be offset by the cost of sustainable survival.

Water use

Undoubtedly one of the major factors determining location of population centres is the available water supply, which must meet the needs of the population centre without the risk of flooding, or lack of water in times of drought. Large dams in Australia are built on rivers flowing through highly productive valley land. Some of this land is flooded by the dam and lost for agricultural use. There is also the question of safety, as most large dams are built on geological fault lines, and the largely unknown effect they have on water tables needs to be considered. Options for future water harvesting schemes may include building reservoirs away from the river and piping water to them, and to consider larger numbers of smaller dams to serve local areas instead of fewer large dams serving a big area.

The issue of pollution of water supplies will be significantly increased as population levels increase, and urban planning will have to find ways to minimise the effects on water storages and river systems, particularly control of runoff from urban and agricultural land. The issue of efficiency of water use will become critically important, and will affect rural and urban areas alike. The planning of efficient water use will become more and more important over time.

Climate modification

As intensity of land use increases, the option of climate modification by extensive grid planting of trees to improve the microclimates at the soil surface, by providing shelter from wind and increasing humidity, could significantly increase food and fibre production. For this option to be effective, planning needs to be done on very large areas, with significant lead times to measure returns for effort invested. This option requires regional planning that involves landholders, and local, state and federal governments. Benefits would be considerable in the medium-to-longer term, and are well worth pursuing.

Conflicts of interest

Planning along these suggested lines will raise conflicts of interest, especially where speculative investments hoping for capital gains on land are involved. The long-term global capability of supplying food and fibre for future generations must take precedence over speculative investments, and population growth forecasts highlight the urgency with which the issue of land use and ownership needs to be addressed.

In terms of local urban planning, the geographic location of future urbanisation will have to take into account the soil types to a much greater extent than at present, as well as all the normal considerations. This may mean that urban property owners will have to accept that the current concept of home landscaping may have to be modified to suit harsher soil conditions in future.

In other words, where a landowner has quality agricultural land close to urban areas, this land should be retained as agricultural, with no possibility of subdividing it for residential use, and the land should be rated at agricultural rates and not at urban rate levels. Urban development should be restricted to lower quality agricultural land.

Defining suitable areas for urbanisation

Guidelines defining suitable areas for urbanisation need to be fully developed at a national level. The current system of defining land classes on productive potential would be a useful starting point, but other issues such as proximity to major transport routes, water and power supply, local climate, land use potential if modified, and population demands will all have to be considered. The future use of the land will need to be carefully planned to sustain the population densities expected in a given area. Also, planning on a national scale is needed to determine where urban areas should be established and their maximum size should be considered as a matter of priority. This planning will need fine tuning in the light of experience and future technological advances in food production.

Overseas planning experience

Unplanned population growth in densely populated areas in other countries has shown clearly that if environmental issues are not considered, then land degradation is inevitable, and may be severe. In all cases, this has reduced the living standards of the inhabitants, and has led to major famines, disease and starvation.

Globally, if land use plans are not developed urgently, and if the plans are not implemented, then the extent of land degradation will increase, diminishing the potential to produce food. In turn, more people will have less to eat. Currently, there is enough food in the world to feed the world's population, but with ever-increasing populations, this option will become less and less available.

Concept for Australia

Planning action is suggested along the following lines:

Collate national soil mapping data, including the soil problems of acidification, sodicity, salinity, erosion and structural decline.

Collate national climatic data.

Collate national demographic data.
Collate national vegetation mapping data.
Use this information as a basis to plan a national approach to land use; specifically:
Plan a national vision for areas of development.
Identify suitable areas for increased productivity.
Plan for the retention and protection of heritage areas.
Plan for funding of capital works on a national scale to enhance primary production and to plan infrastructure support for new urban development.
Plan legislative changes necessary to enable national planning and implementation to proceed.
Improve skills of current and future primary producers by all means available.
Put in place a framework that allows primary producers to optimise sustainable production through sufficient farm gate returns to fund capital and labour inputs necessary for sustainable land care (currently this is very difficult).

Summary

The series of dry years since 2000 has forcefully shown the critical need to address planning issues with regard to soil and water use and agricultural production. These issues must be given a very high priority to meet the ever growing demand for food on a global scale.

The extent to which urbanisation is permitted must be based on the ability to provide urban development with a reliable water supply, while retaining quality land for agricultural production. Dwindling food and energy supplies are a serious global issue, which will mean that more food will have to be produced close to where it is consumed, especially perishable food. This will require an urgent re-assessment and sound long-term planning of soil and water use, and location and size of urban areas.

Appendices

Appendix 1. Preferred pH(water) ranges for some agricultural crops

Field crops					
Barley	6.0–8.5	Wheat	5.5–8.5	Oats	4.5–8.0
Triticale	4.5–8.5	Ryecorn	5.0–7.5	Rice	5.0–6.5
Canola	6.0–7.5	Sunflowers	6.0–8.0	Linseed	5.0–7.0
Lupins	5.0–7.0	Soybeans	6.0–7.0	Peas	6.0– 7.5
Vetch	5.0–7.0	Maize	5.5–7.5	Millet	5.0–6.5
Fruit crops					
Apple	6.0–7.0	Pear	6.5–7.5	Peach	6.0–7.5
Nectarine	5.5–7.0	Almond	6.0–7.0	Cherry	6.5–7.5
Plum	6.5–7.5	Apricot	5.5–6.5	Citrus	6.0–7.5
Grape	5.5–6.5	Walnut	6.0–8.0	Passionfruit	6.0–8.0
Raspberry	6.0–6.5	Strawberry	6.5–7.5	Melon	7.0–8.0
Watermelon	5.0–5.5	Cantaloupe	6.0–6.5		
Vegetable crops					
Bean	5.5–7.5	Beetroot	7.0–8.0	Broccoli	6.5–7.5
Brussels sprouts	6.5–7.5	Cabbage	6.0–7.0	Carrot	6.5–7.5
Cauliflower	6.0–7.0	Celery	6.0–7.0	Cucumber	5.5–7.0
Garlic	5.5–8.0	Lettuce	6.5–7.5	Onion	6.0–7.0
Parsnip	6.5–7.5	Peas	6.0–7.5	Potato	5.0–6.0
Pumpkin	5.5–7.0	Spinach	7.0–8.0	Sweet corn	5.5– 7.5
Tomato	6.0–7.0	Turnip	5.5–7.0		
Pastures and turf					
Clovers	5.5–7.0	Medics	6.5–8.5	Lucerne	6.0–8.0
Serradella	5.5–7.0	Ryegrass	5.5–7.0	Phalaris	6.0–8.0
Cocksfoot	5.0–7.5	Fescue	5.0–7.0	Bent grass	5.0–6.0
Couch grass	6.0–7.0	Gypsophila	6.0–7.5		
Cut flowers					
Waratah	5.0–6.5	Protea	4.5–6.0	Carnation	6.0–7.0
Chrysanthemum	6.0–7.0	Rose	6.0–7.5	Daffodil	6.0–6.5
Gladiolus	6.0–8.0	Tulip	6.0–7.0	Liliums	5.5–7.0
Freesia	6.0–7.5				

Appendix 2. The pH (H_2O) scale

pH reaction	pH value	pH reaction	pH value
extremely acid	<4.5	slightly alkaline	7.1–7.9
very strongly acid	4.5–4.9	moderately alkaline	8.0–8.5
strongly acid	5.0–5.5	strongly alkaline	8.6–9.0
moderately acid	5.6–6.0	very strongly alkaline	9.1–9.5
slightly acid	6.1–6.9	extremely alkaline	>9.5
neutral	7.0	—	—

Appendix 3. Electrical conductivity (in dS/m)

Soil salinity refers to the free salts in the soil solution. Soils with EC values less than 0.16 dS/m (approximately 0.05% TSS) are generally regarded as sufficiently low to have harmless salinity. However, soil texture and other factors influence the salt tolerance of plants.

Published data on the salt tolerance of agricultural crops refer to the electrical conductivity of the saturation extract (ECe). However, obtaining the saturation extract ECe in the laboratory is time consuming and hence not practical for the rapid estimation of the salinity of large numbers of samples. For this reason the EC of a 1:5 soil/water suspension is used and may be converted to an approximate ECe value by multiplying by appropriate factors for different soil textures as shown below:

Soil texture	**Multiplication factor**
Sands, loamy sands	13
Sandy loams, fine sandy loams	11
Loams, very fine sandy loams, silty loams, sandy clay loams	10
Clay loams, silty clay loams, very fine sandy clay loams, fine sandy clay loams, sandy clays, silty clays, light clays	9
Light medium clays	8
Medium clays	7
Heavy clays	6

Appendix 4. Salt tolerance of some agricultural crops showing maximum ECe values in dS/m for no yield reduction

Main source: Ayers and Westcot (1985).

Sensitive (ECe 0–1.9 dS/m)		**Moderately tolerant** (ECe 2.0–3.9 dS/m)		**Tolerant** (ECe >3.9 dS/m)	
Field crops					
Faba beans	1.6	Rice	3.0	Sorghum	4.0
Linseed, Maize	1.7			Soybean	5.0
				Safflower	5.3
				Wheat	6.0
				Barley	8.0
Pasture, turf and fodder crops					
Berseem, Red, White, Sub. and strawberry	1.5	Lucerne	2.0	Phalaris	4.6
Clovers		Vetch	3.0	Perennial ryegrass	5.6
Bent grass	1.7			Tall wheat grass	7.5
Vegetable crops					
Beans, Carrots, Celery, Peas	1.0	Spinach, Watermelon	2.0	Beets	4.0
Onion	1.2	Cantaloupe	2.2		
Lettuce	1.3	Broadbeans	2.3		
Potato	1.7	Cucumber, Tomato	2.5		
Cabbage, Cauliflower	1.8	Broccoli	2.8		
Strawberry	1.0	Fig, Grape (Thompson spp.), Olive, Pomegranate	2.7		
Grape (*Vitis* spp.), Plum	1.5				
Apple, Apricot, Lemon, Orange, Peach, Pear	1.7				
Grapefruit	1.8				

Appendix 5. Total soluble salts

Soil salinity may also be expressed as Total Soluble Salts (TSS). This is useful when the proposed cropping future is not yet decided.

Total soluble salt	**Description**	**Interpretation**
<0.05	Low and harmless	Harmless for all plant species
0.05–0.08	Slightly higher than normal	May cause growth reduction in salt sensitive species in ligher textured soils
0.09–0.16	Higher than normal	Likely to cause growth reduction in salt sensitive species and may cause growth reduction in moderately salt tolerant in lighter textured soils
0.17–0.24	Unfavourable	Expected to cause growth reduction in salt sensitive species and moderately salt tolerant species
0.25–0.33	High and harmful	May cause growth reduction in salt tolerant species in lighter textured soils
>0.33	Very high and harmful	Harmful to all but very salt tolerant species

Appendix 6. Chloride (as % NaCl)

Chloride is a particular ion that is commonly a major constituent of the total soluble salts (TSS) present in a soil. Where chloride is only a minor constituent of TSS, the remainder of the TSS probably consists of salts derived from the recent use of gypsum, fertiliser etc. and as such, is unlikely to cause salt damage in the longer term. Descriptive terms for chloride ranges (expressed as % NaCl) are as follows:

	Sands to sandy loams	**Clay loams**	**Clays**
Low (normal)	<0.02	<0.03	<0.05
Slightly saline: indicates poor drainage	0.02–0.07	0.03–0.10	0.05–0.15
Moderately saline: germination and growth may be affected	0.08–0.20	0.11–0.30	0.16–0.40
Highly saline: difficulty in establishment; drainage required	>0.20	>0.30	>0.40

Appendix 7. Organic carbon (%) and total nitrogen (%)

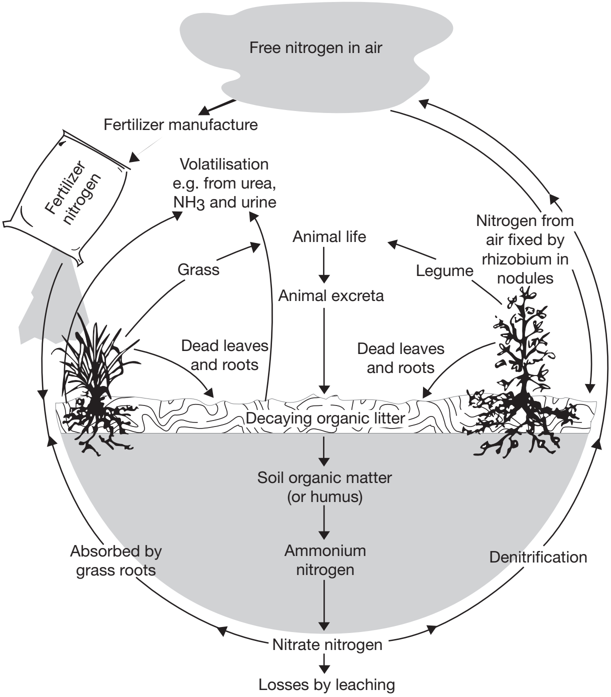
Low levels of organic carbon indicate low organic matter contents in soils, thus providing a guide to low fertility. ‘Normal’ levels of organic carbon in soils vary according to the pasture or crop type involved. However, rough guidelines for organic matter (%) calculated from organic carbon are as follows:

	Crops	**Pastures**	**Crops**	**Pastures**
	Low rainfall	Low rainfall	High rainfall	High rainfall
Low	<1.5	<3.0	<2.5	<5.0
Normal	1.5–2.5	3.0–4.5	2.5–5.0	5.0–10.0
High	>2.5	>4.5	>5.0	>10.0

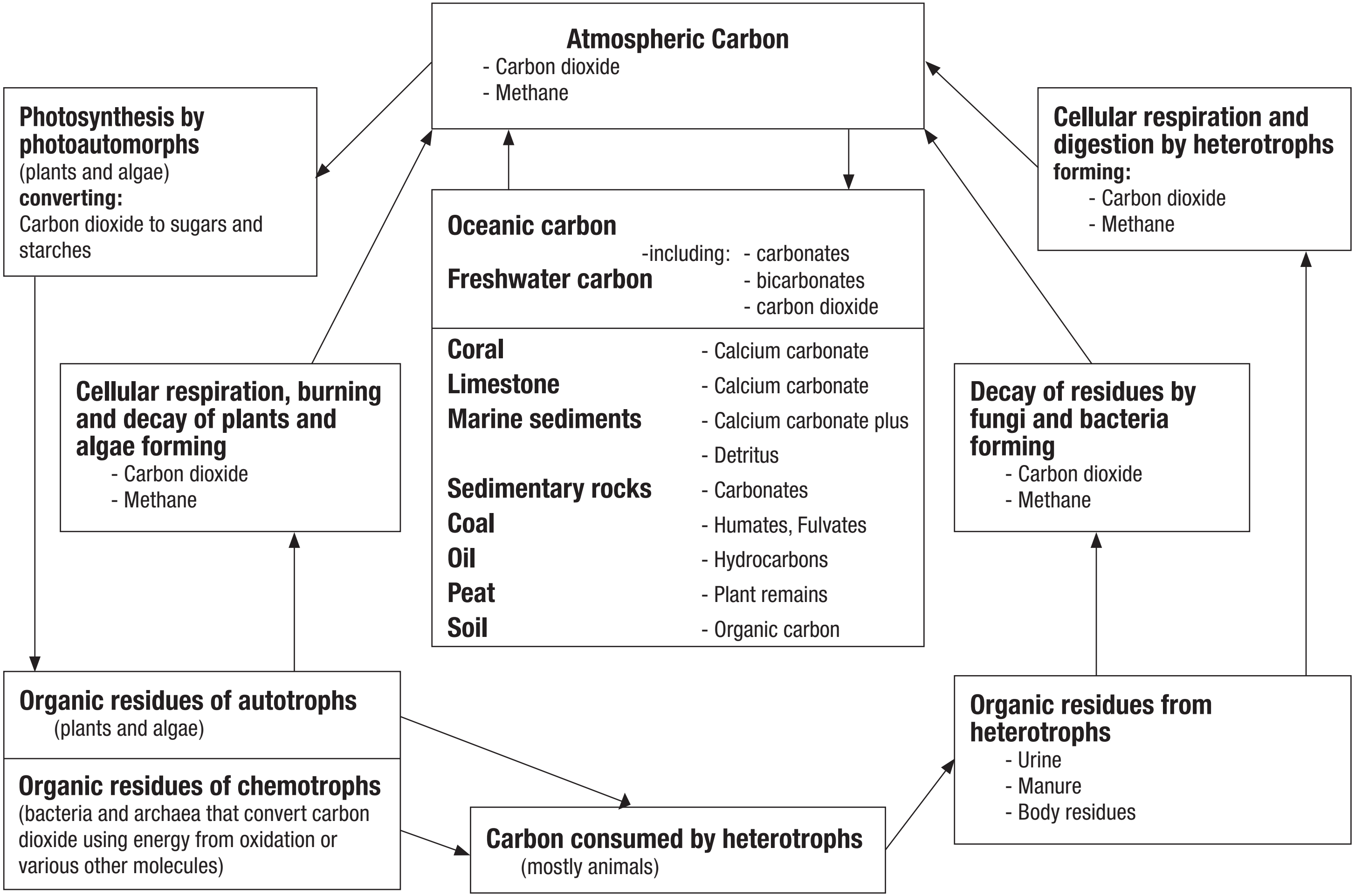
The ratio of carbon to nitrogen lies between 10 and 15 for most soils. Peaty soils have high C/N rations; often as high as 50 due to the high plant component. Soils with C/N ratios of greater than 20 tend to be poorly nitrified.

Note. Organic matter % can be derived from organic carbon using the equation: OM = organic carbon × 1.72.

Appendix 8. The nitrogen cycle



Appendix 9. The chemistry of the carbon cycle



Appendix 10. Mathematical conversions

(1) pH

pH (in calcium chloride) is generally about 0.7 pH units lower than pH (in water). This is only an average figure.

Certain soils, particularly alkaline soils, may be as much as 1.2 pH units lower. However, for saline soils, the difference between the two measurements can be very small.

(2) Electrical conductivity

Electrical conductivity (EC) is expressed in deciSiemens per meter (dS/m).

0.1 dS/m = 100 µS/cm = 100 µmho/cm

To convert from EC to total soluble salts (TSS) in ppm or per cent, use the following equations:

TSS (ppm) = EC (dS/m) × 2970

or TSS (%) = EC (dS/m) × 0.297

(3) Chloride (as % sodium chloride)

To calculate the percentage of chloride (Cl) from the TSS:

% Cl ÷ % TSS

(4) Exchangeable aluminium

Using the existing methodology, it is not possible to calculate the percentage aluminium from the cation exchange capacity.

(5) Exchangeable cations

(i) Exchangeable calcium (Ca)

1 milliequivalent/100 grams soil
= 1 meq/100 g
= 200 ppm
= 200 µg/g

(ii) Exchangeable magnesium (Mg)

1 meq/100 g
= 120 ppm
= 120 µg/g

(iii) Exchangeable sodium (Na)

1 meq/100g
= 230 ppm
= 230 µg/g

(iv) Exchangeable potassium (K)
1 meq/100g
= 390 ppm
= 390 µg/g

(v) % calcium

$$\% \text{ Ca} = \frac{\text{exchangeable Ca (meq/100 g)}}{\text{sum of 4 cations (meq/100 g)}} \times \frac{100}{1}$$

(vi) % magnesium

$$\% \text{ Mg} = \frac{\text{exchangeable Mg (meq/100 g)}}{\text{sum of 4 cations (meq/100 g)}} \times \frac{100}{1}$$

(vii) % sodium

$$\% \text{ Na} = \frac{\text{exchangeable Na (meq/100 g)}}{\text{sum of 4 cations (meq/100 g)}} \times \frac{100}{1}$$

(viii) % potassium

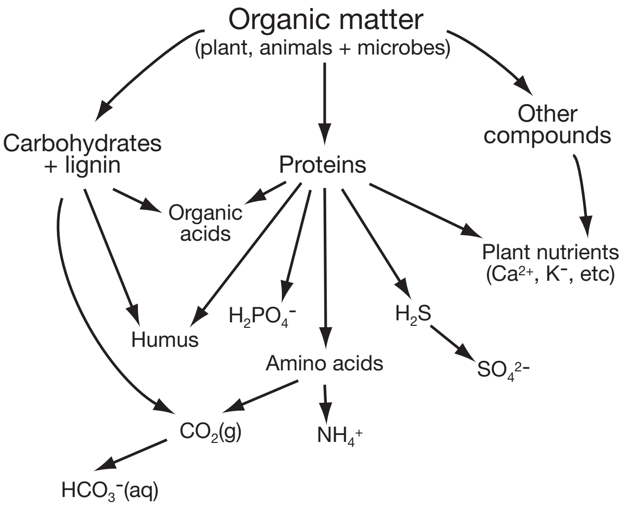
$$\% \text{ K} = \frac{\text{exchangeable K (meq/100g)}}{\text{sum of 4 cations (meq/100g)}} \times \frac{100}{1}$$

(6) Organic carbon
To calculate organic matter from organic carbon:
Organic carbon × 1.72 = organic matter

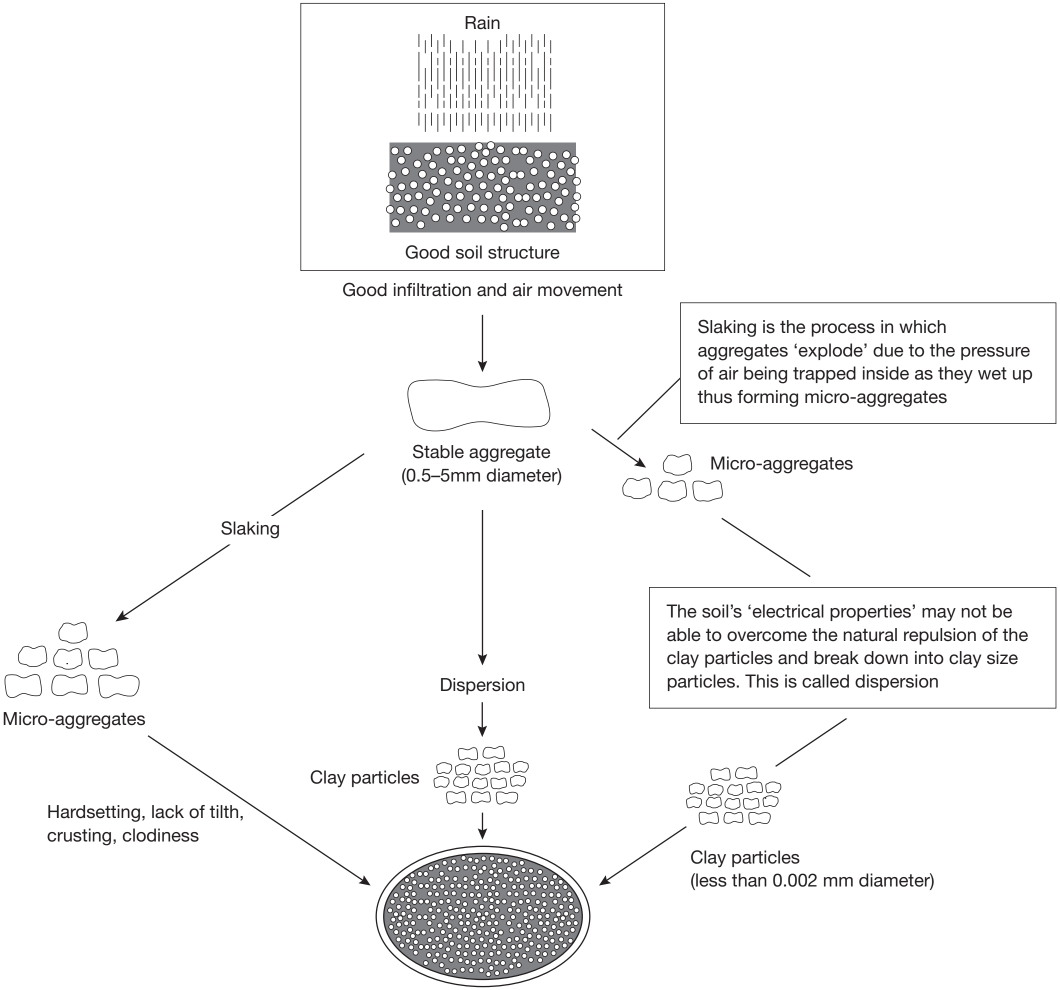
(7) Neutralising Value (%) in lime
A theoretical Neutralising Value can be calculated by:
$CaCO_3$ % + [2.5 × MgO] % = Neutralising Value

(8) Effective Neutralising Value (%) in lime
Neutralising Value × [(% material greater than 0.85 mm × 0.1) + (% material between 0.85 and 0.30 mm × 0.6) + (% material less than 0.30 mm × 1.0)] = Effective Neutralising Value

Appendix 11. The organic matter cycle



Appendix 12. The different processes of slaking and dispersion



Slaking is the process in which aggregates ‘explode’ due to the pressure of air being trapped inside as they wet up thus forming micro-aggregates

The soil’s ‘electrical properties’ may not be able to overcome the natural repulsion of the clay particles and break down into clay size particles. This is called dispersion

Appendix 13. Organic matter levels relative to rainfall for surface soils (0–10 cm)

Level of organic matter	**Pasture: low rainfall area**	**Pasture: high rainfall area (approx. 650 mm)**
Low	<3	<5
Normal	3.0–4.5	5–10
High	>4.5	>10

Appendix 14. Nutrient deficiencies in plants: a quick guide

Source: Williams C. H., and Collwell J. D. (1979).

Symptoms appear first in the OLDEST leaves

Nitrogen	general yellowing; stunting; premature maturity
Magnesium	patchy yellowing; brilliant colours especially around edge
Potassium	scorched margins; spots surrounded by pale zones
Molybdenum	mottling over whole leaf but little pigmentation; cupping of leaves and distortion of stems
Cobalt	legumes only, as for nitrogen

[Excess salt marginal scorching, generally no spotting]

Symptoms appear first in either the OLDEST or YOUNGEST leaves

Manganese	interveinal yellowing; veins pale green, diffuse; water-soaked spots; worst in dull weather

Symptoms appear first in the YOUNGEST leaves

Calcium	tiphooking, blackening and death
Sulphur	yellowing; smallness; rolled down; some pigmentation
Iron	interveinal yellowing; veins sharply green, youngest leaves almost white if severe
Copper	dark blue-green; curling; twisting; death of tips
Zinc	smallness; bunching; yellow-white mottling
Boron	margins chlorotic; crumpling; blackening; distortion

Appendix 15. Average nutrient content of animal manures (as a percentage)

Source: Glendinning (1990).

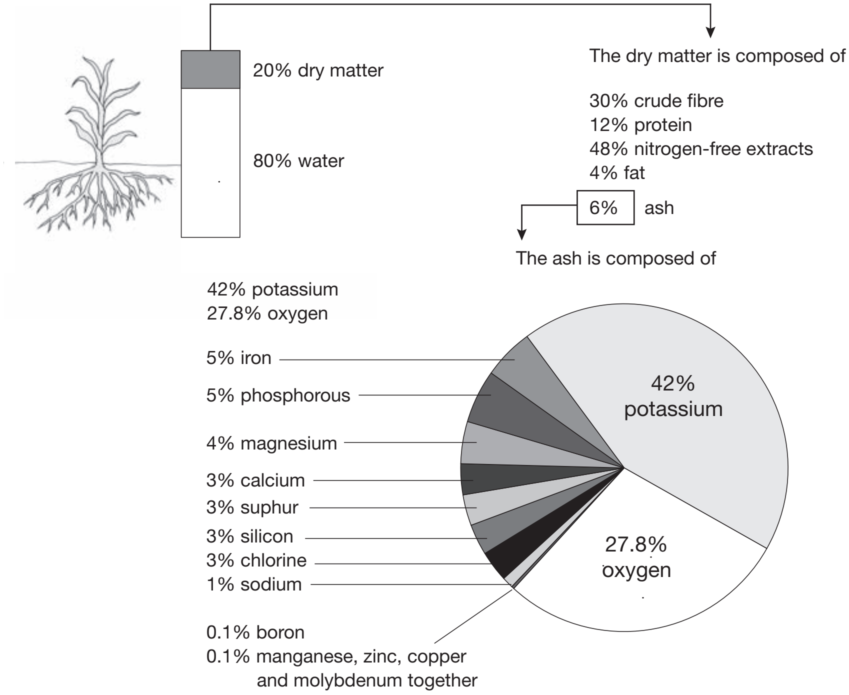
Analysis	**Fowl**	**Pig**	**Sheep**	**Cow**	**Horse**
Nitrogen	0.8–2.6	0.6–1.2	0.5–1.4	0.8–1.1	0.7–1.2
Phosphorus	0.6–2.0	0.5–0.8	0.4–1.0	0.5–0.8	0.5–0.9
Potassium	0.4–1.2	0.4–1.0	0.5–0.7	0.4–1.3	0.4–1.3
Magnesium	0.13	0.03	0.13	0.11	0.11
Calcium	0.38	0.19	0.21	0.27	0.29
Sulphur	0.06	0.03	0.06	0.036	0.036
Trace elements					
Copper	trace	trace	trace	trace	trace
Manganese	trace	trace	trace	trace	trace
Zinc	trace	trace	trace	trace	trace
Chlorine	0.08	0.03	0.08	0.03	0.08
Boron	0.16	trace	0.16	0.16	0.16
Organic matter	30.70	15.50	30.70	16.74	27.06
Moisture	64.82	77.56	64.82	81.33	68.85
Ash	4.72	6.02	4.72	2.06	6.70

Appendix 16. Mineral elements in plants

Source: Epstein (1972).

Element	Range of concentrations Dry weight basis	Remarks
Nitrogen %	0.50–6.00	Essential element
Phosphorus %	0.15–0.50	
Sulphur %	0.10–1.50	
Potassium %	0.80–8.00	
Calcium %	0.10–6.00	
Magnesium %	0.05–1.00	
Iron ppm	20–600	Essential micronutrient
Manganese ppm	10–600	
Zinc ppm	10–250	
Copper ppm	2–50	
Nickel ppm	0.05–5.0	
Boron ppm	0.2–800	
Chlorine ppm	10–80 000	
Molybdenum ppm	0.1–10	
Cobalt ppm	0.08–0	Essential in all nitrogen-fixing systems
Sodium %	0.001–8.0	Essential for some plants, often beneficial
Silicon %	0.1–10	
Aluminium ppm on acid soils	0.1–800	Not known to be essential, often toxic to plants grown in acid soils

Appendix 17. The average composition of the plant



Appendix 18. The influence of chemical fertilisers on pH

Source: Queensland Department of Primary Industry.

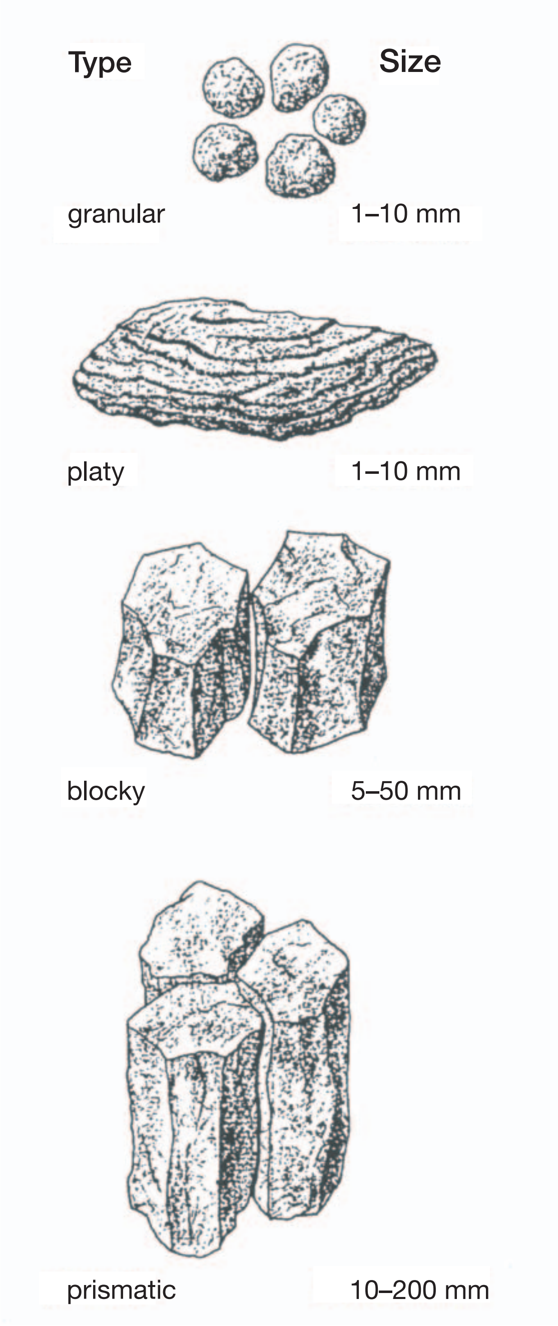
Fertiliser	**Solubility in cold (15°C) water (grams per litre)**	**Rate of pH change**	**Influence on pH**
Ammonium nitrate	1183	Rapid	Acidic
Ammonium sulphate	706	Rapid	Acidic
Calcium carbonate	0.015	Slow	Alkaline
Calcium chloride	350	Rapid	Alkaline
Calcium hydroxide	1.85	Medium	Alkaline
Calcium nitrate	2660	Rapid	Alkaline
Calcium sulphate (gypsum)	2.41	Medium	Neutral
Dolomite	0.01	Slow	Alkaline
Magnesium carbonate	0.11	Slow	Alkaline
Magnesium sulphate (Epsom salts)	710	Rapid	Neutral
Monoammonium phosphate	227	Rapid	Acidic
Phospheric acid	5480	Rapid	Acidic
Potassium chloride	238	Rapid	Alkaline
Potassium nitrate	133	Rapid	Neutral
Superphosphate – single	–	Slow	Acidic
Superphosphate – triple	–	Medium	Acidic
Urea	1000	Rapid	Acidic

Appendix 19. Physical properties of soil

Property	**Coarse sand**	**Fine sand**	**Silt**	**Clay**
Water holding capacity	very low	medium	high	very high
Capillarity	very low	medium	good	very good
Drainage rate	very fast	moderate	slow	very slow
Nutrient absorption capacity	very low	low	moderate	high
Cohesion and plasticity	none	very low	moderate	high
Ease of compaction	very low	low	moderate	high
Inherent fertility	very low	low	moderate	high
Aeration	very good	moderate	poor	very poor
Relative temperature	warm	cool	cold	very cold
Ease of pollutant leaching	very high	good	moderate	low

Appendix 20. The four main types of structure that occur in mineral soils

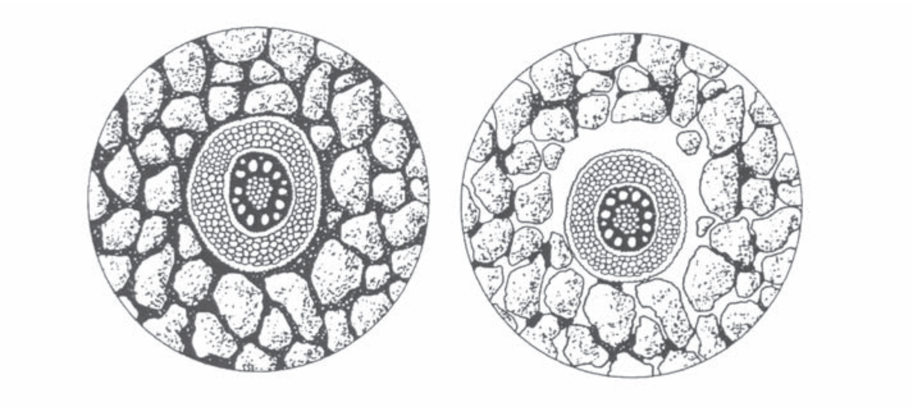
Source: Dubbin (2001).



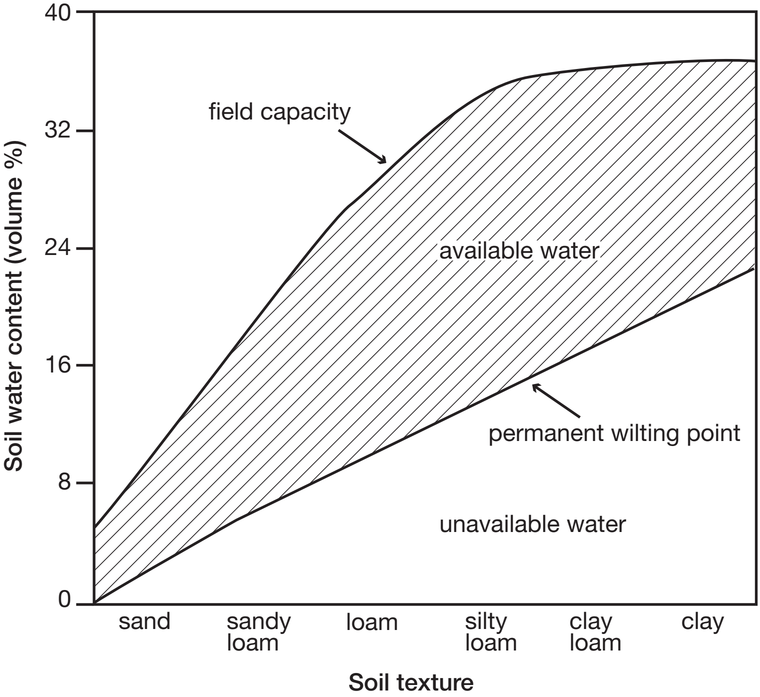
Appendix 21. Plant–soil–water relationships

Source: Dubbin (2001).

As soil water content decreases, less water is in contact with the root surface.



Field capacity, permanent wilting point and available water vary with soil texture.



Appendix 22. Readily available water required

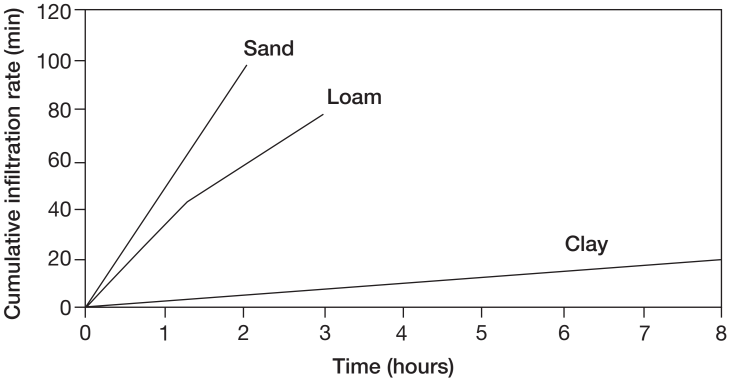
Source: NSW Agriculture. kPa is pressure in kilopascals.

Soil texture	**Readily available water mm/mm**				
	A -8 to -20 kPa	B -8 to -40 kPa	C -8 to -60 kPa	D -8 to -100 kPa	E -8 to -1500 kPa
Sand	35	35	35	40	60
Sandy loam	45	60	65	70	115
Loam	50	70	85	90	150
Clay loam	30	55	65	80	150
Light clay	25	45	55	70	150
Medium, heavy clay	24	45	55	65	140

Column A is for water sensitive crops such as vegetables.
Column B is for most fruit crops and table grapes.
Column C is for wine grapes, most perennial pastures and irrigated field crops.
Column D is for lucerne, annual pastures and winter cereals.
Column E is for crops suitable for new rainfall areas.

Appendix 23. Cumulative infiltration of water

Source: NSW Agriculture.

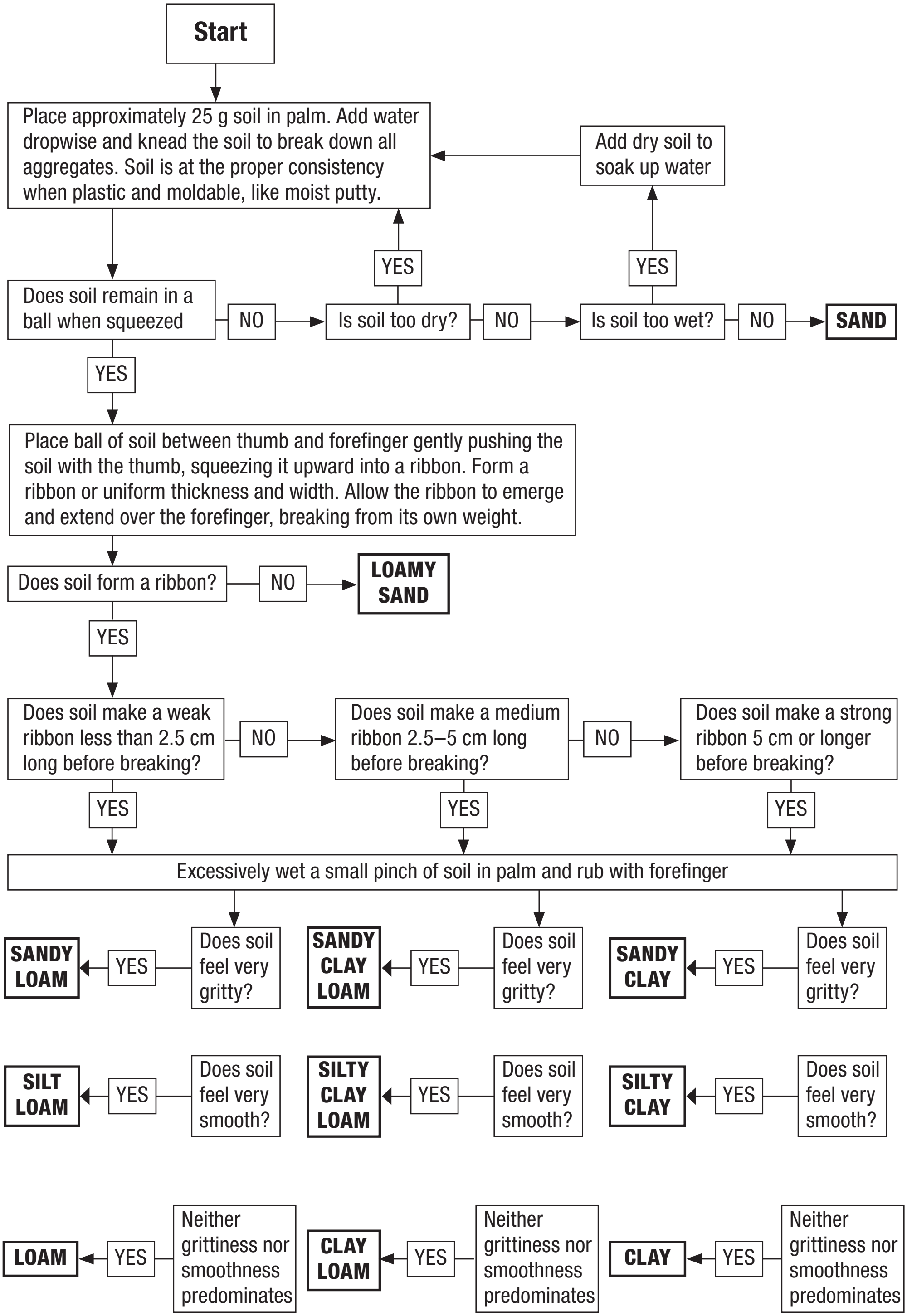


Appendix 24. Average infiltration rates for some soil types

Source: NSW Dept. Land and Water Conservation.

Texture group	Application rate		Infiltration rate mm/hr
	Average soil structure	Well-structured soil	
Sands	50	65	50–700
Sandy loam	30	45	50–700
Loam	30	45	5–300
Clay loam	10	25	2.5–300
Light clay	2.5	5	0.5–40
Medium, heavy clay	2.5	5	0.1–40

Appendix 25. Assessing soil texture by feel



Place approximately 25 g soil in palm. Add water dropwise and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and moldable, like moist putty.

Add dry soil to soak up water

Does soil remain in a ball when squeezed

Is soil too dry?

Is soil too wet?

Place ball of soil between thumb and forefinger gently pushing the soil with the thumb, squeezing it upward into a ribbon. Form a ribbon or uniform thickness and width. Allow the ribbon to emerge and extend over the forefinger, breaking from its own weight.

Does soil form a ribbon?

Does soil make a weak ribbon less than 2.5 cm long before breaking?

Does soil make a medium ribbon 2.5–5 cm long before breaking?

Does soil make a strong ribbon 5 cm or longer before breaking?

Excessively wet a small pinch of soil in palm and rub with forefinger

Does soil feel very gritty?

Does soil feel very smooth?

Neither grittiness nor smoothness predominates

Appendix 26. Texturing soils using a soil bolus

Texture symbol	Field texture grade	Behaviour of moist bolus	Approximate clay content (%)
S	Sand	Coherence nil to very slight, cannot be moulded; sand grains of medium size; single sand grains adhere to fingers.	less than 5%
LS	Loamy sand	Slight coherence; sand grains of medium size; can be sheared between thumb and forefinger to give a minimal ribbon of about 5 mm.	approx. 5%
CS	Clayey sand	Slight coherence; sand grains of medium size; sticky when wet; many sand grains stick to fingers; will form a minimal ribbon of 5–15 mm; discolours fingers with clay stain.	5–10%
SL	Sandy loam	Bolus coherent but very sandy to touch; will form a ribbon of 15–25 mm; dominant sand grains are of medium size and are readily visible.	10–20%
FSL	Fine sandy loam	Bolus coherent; fine sand can be felt and heard when manipulated; will form a ribbon of 13–25 mm; sand grains clearly evident under a hand lens.	10–20%
SCL	Ligh sandy clay loam	Bolus strongly coherent but sandy to touch; sand grains dominantly medium-sized and easily visible; will form a ribbon of 20–25 mm.	15–20%
L	Loam	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or ‘silkiness’; may be somewhat greasy to the touch if much organic matter present; will form a ribbon of 25 mm.	approx. 25%
Lfsy	Loam, fine sandy	Bolus coherent and slighty spongy; fine sand can be felt and heard when manipulated; will form a ribbon of approx. 25 mm.	approx. 25%
ZL	Silty loam	Coherent bolus; very smooth to often silky when manipulated; will form a ribbon of approx. 25 mm.	approx. 25% and with silt approx. 25% or more
SCL	Sandy clay loam	Strongly coherent bolus, sandy to the touch; medium-sized sand grains visible in finer matrix; will form a ribbon of 25–40 mm.	20–30%
CL	Clay loam	Coherent plastic bolus, smooth to manipulate; will form a ribbon of 40–50 mm.	30–35%
CLS	Clay loam, sandy	Coherent plastic bolus; medium-sized sand grains visible in finer matrix; will form a ribbon of 40–50 mm.	30–35%
ZCL	Silty clay loam	Coherent smooth bolus, plastic and often silky to the touch; will form a ribbon of 40–50 mm.	30–35% and with silt 25% or more

Texture symbol	Field texture grade	Behaviour of moist bolus	Approximate clay content (%)
FSCL	Fine sandy clay loam	Coherent bolus; fine sand can be felt and heard when manipulated; will form a ribbon of 38–50 mm.	30–35%
SC	Sandy clay	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form a ribbon of 50–75 mm.	35–40%
ZC	Silty clay	Plastic bolus; smooth and silky to manipulate; will form a ribbon of 50–75 mm.	35–40%
LC	Light clay	Plastic bolus; smooth to touch; slight resistance to shearing; will form a ribbon of 50–75 mm.	clay: 35–40% silt: 25%+
LMC	Light medium clay	Plastic bolus; smooth to touch; slight to moderate resistance to forming a ribbon; will form ribbon approx. 75 mm.	40–45%
MC	Medium clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has moderate resistance to forming a ribbon; will form ribbon of 75 mm or more.	45–55%
MHC	Medium heavy clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has moderate to firm resistance to forming a ribbon; will form ribbon of 75 mm or more.	50%+
HC	Heavy clay	Smooth plastic bolus; can be moulded into a rod without fracturing; has firm resistance to forming a ribbon; will form ribbon of 75 mm or more.	50%+

Appendix 27. Soil colour

The colour of a soil is an important descriptive characteristic of a soil. Colours also provide an indication of soil drainage, degree of leaching and organic matter content.

Soil colour is generally determined by organic matter and the iron compounds in the soil. Decayed organic matter gives the soil a dark colour. In freely draining soil (oxidising environments), soil colour can be attributed to: humus (black); iron (red); and silicates and salts (white) (Figure 27). The colours of poorly drained soils that are in reducing environments (rather than oxidising) tend to be bluey-green. Soil with little iron in them are pale grey in colour (Corbett 1969).

Summary of soil colour and its implications

Source: Queensland Department of Primary Industries (unpublished data).

Soil colour	Interpretation
Topsoil	
Dark brown surface	Indicates presence of organic matter (cultivation can disturb this feature in cropping soils)
A2 horizon (pale middle horizon between topsoil and subsoil)	The pale colour indicates the strong leaching of iron and manganese compounds into the subsoil. This layer tends to be poorly structured and becomes waterlogged in winter, sets hard in summer and is acidic.
Subsoil	
Bright red or yellow	Well-drained and aerated soils. The presence of iron oxides gives the soil its red colour. The redness is free ferric oxide produced under oxidising conditions, and found in wet warm climates and in regions with summer drought. The redness tends to disappear from waterlogged soils.
Pale grey, olive or blue	Poorly drained soils that lack oxygen
Mottled red, yellow and/or grey	Mottling is common in north-east Victoria and in high rainfall zones. The mottles result from seasonal waterlogging. During anaerobic conditions the iron is reduced to a ferrous state ($Fe^{3+} \rightarrow Fe^{2+}$). This results in a grey/blue/green pigment ‘gleying’. This reduced iron can be leached out of a soil, leaving bleached areas with no pigment at all. Under aerobic conditions, the red and yellow iron minerals develop, converting ferrous (Fe^{2+}) to ferric cations (Fe^{3+}). The redder and yellower areas indicate the drier zones where more oxygen is available.
Dark brown and black	The dark brown and black soils are rich in humus, but the colour of the soil does not necessarily indicate fertility, although the lighter colour soils do lack organic matter.

The colour of a soil is described using the Munsell Colour Chart. This provides a standard system for categorising soils based on colour. The colour test is done on a freshly broken surface of moist soil. All samples are wetted up so as to maintain a uniform moisture content as the moisture content of a soil can vary from dry to moist at any given time. This ensures a consistent sampling approach.

References

Ayers, R. S., and Westcot, D. W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 rev. 1 (Rome.)

Black, C. A. (1968). '*Soil-Plant Relationships*.' (Wiley: New York.)

Corbett, J. R. (1969). '*The Living Soil: The Processes of Soil Formation*.' (Martindale Press: West Como, Australia.)

Dubbin, W. (2001). '*Soils*.' (The Natural History Museum: London.)

Epstein, E. (1972). '*Mineral Nutrition of Plants: Principles and Perspective*.' (Wiley: New York.)

Glendinning, J. S. (Ed.) (1990). '*Fertilizer Handbook*.' Rev. ed. (Incitec.)

Hall, R. (1997). *Soil Sense Notes*. (Department of Agriculture, Victoria.)

Handreck, K. (1977). *Soils: an outline of their properties and management*. CSIRO Division of Soils, Discovering Soils No. 1. (CSIRO Publishing: Melbourne.)

Handreck, K. (2001). '*Gardening Down-Under: A Guide to Healthier Soils and Plants*.' 2nd edn. (CSIRO Publishing: Melbourne.)

Hazelton, P., and Murphy, B. (2007). '*Interpreting Soil Test Results*.' (CSIRO Publishing: Melbourne.)

Isbell, R. F. (2002). '*The Australian Soil Classification*.' Rev. edn. (CSIRO Publishing: Melbourne.)

Jacquier, D. W., McKenzie, N. J., Brown, K. L., Isbell, R. F., and Paine, T. A. (2000). *The Australian Soil Classification: An Interactive Key*. (CSIRO Publishing: Melbourne.)

Jayawardane, N. S., and Stewart, B. A. (1995). '*Subsoil Management Techniques, Advances in Soil Science*.' (Lewis Publishers: Boca Raton, Fla. USA)

Lee, K. E. (1985). '*Earthworms, Their Ecology and Relationships with Soils and Land Use*.' (Academic Press: Sydney.)

McKenzie, N. (2004). '*Australian Soils and Landscapes: An Illustrated Compendium*.' (CSIRO Publishing: Melbourne.)

McLachlan, K. D. (Ed.) (1974). '*Handbook on Sulphur in Australian Agriculture.*' (CSIRO Publishing: Melbourne.)

Naidu, R., Sumner, M. E., and Rengasamy, P. (Eds) (1995). *Australian Sodic Soils: Distribution, Properties, and Management*. (CSIRO Publishing: Melbourne.)

Peverill, K. I., Sparrow, L. A., and Reuter, D. J. (Eds) (1999). *Soil Analysis: An Interpretation Manual*. (CSIRO Publishing: Melbourne.)

Price, G. H. (Ed.) (2006). '*Australian Soil Fertility Manual.*' 3rd edn. Fertilizer Industry Federation of Australia. (CSIRO Publishing: Melbourne.)

Russell, J. S., and Isbell, R. F. (Eds) (1986). *Australian Soil: The Human Impact*. (University of Queensland Press and Australian Society of Soil Science: St Lucia, Qld.)

Shepherd, T. G., Ross, G. W., Basher, L. R., and Saggar, S. (2000). '*Soil Management Guidelines for Sustainable Cropping.*' (Manaaki Whenua Press: New Zealand.)

Spafford, W. J. (1993). '*Fertilisers and Soil Amendments.*' (Department of Agriculture of South Australia, Adelaide.)

Underwood, E. J. (1956). '*Trace Elements in Human and Animal Nutrition.*' (Academic Press: New York.)

Vincent, S. (1969). '*Trace Elements in Agriculture.*' (Van Nostrand Reinhold Co.: New York.)

Windust, A. (1994). '*Worms Downunder Downunder: For Farm, Garden, Schools, Profit and Recycling.*' (Allscape: Mandurang, Victoria)

Zuckerman, L., and Segalen, P. (Transl.) (1977). *Trace Elements in Soils by A. Huguette and M. Pinta*. (Elsevier: New York.)

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