Food, Agriculture, and the Environment Discussion Paper 17

The Role of Fertilizer in Sustaining Food Security and Protecting the Environment to 2020

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

2020 VISION

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Foreword

The world's population is growing by about 90 million a year. To feed future generations adequately will require gains in output that are only possible with a plentiful supply of plant nutrients to sustain the needed increases in crop yields. But in recent years heavy use of fertilizer has come under attack for its possible contribution to environmental ills ranging from nitrate leaching to greenhouse gas emissions to wasteful use of hydrocarbons. There is no doubt that misuse of fertilizer (organic or chemical) can cause environmental damage, but as the authors point out here, failure to replenish nutrients in soils, especially nutrient-poor tropical soils, "can initiate and perpetuate a downward spiral of soil degradation, increased deforestation, and depletion of the natural resource base," ultimately leading to increased poverty, hunger, malnutrition, and environmental degradation.

In this discussion paper, part of IFPRI's 2020 Vision initiative, Balu Bumb and Carlos Baanante of the International Fertilizer Development Center (IFDC) review past trends in fertilizer use, estimate future needs, and assess technical and policy measures for dealing with environmental and energy concerns related to fertilizer use. We at IFPRI acknowledge with gratitude IFDC's support of the 2020 Vision initiative and their willingness to contribute the valuable time of their staff in preparing this paper. We believe that policymakers will find its contents useful in making informed decisions to help meet the challenge of reducing hunger and poverty by 2020.

Per Pinstrup-Andersen
Director General, IFPRI

1. Introduction

In the mid-1960s, when projections of global starvation were not uncommon, no one questioned the role of fertilizer[1] in promoting food production in the food-deficit countries. On the contrary, fertilizer was an integral part of the technological trinity—seed, water, and fertilizer—responsible for bringing about the Green Revolution that helped many densely populated countries, including India and China, achieve food self-sufficiency in a short span of 20 to 25 years. In the early 1990s, however, fertilizer became the target of criticism mainly because of heavy use in the developed countries where it was suspected of having an adverse impact on the environment through nitrate leaching, eutrophication, greenhouse gas emissions, and heavy metal uptakes by plants and soils. Consequently, fertilizer use per se was mistakenly identified as an enemy of the environment.

Like any other source of plant nutrients, fertilizer can contribute to environmental damage unless managed properly.[2] Nonetheless, fertilizer is an important and sometimes indispensable source of the nutrients required for plant growth and food production. In both traditional and modern farming systems, harvested crops remove nutrients from the soil. Unless these nutrients are replenished in adequate quantities, the natural resource base may be degraded through nutrient depletion and soil degradation, thereby increasing the likelihood of deforestation. Because natural processes can replenish only limited quantities of the nutrients removed, these nutrients must be supplied through external sources. Moreover, the natural supply of nutrients in the soil cannot sustain high crop yields; using improved crop varieties to increase crop yields mandates that nutrients must be supplied from external sources. Thus fertilizer use plays an important role in raising crop yields and sustaining the natural resource base.

In addition to land, water, solar radiation, and carbon dioxide (CO_2), plants need an adequate supply of nutrients for photosynthesis. While supplies of solar radiation and CO_2 are unlimited, no natural sources can provide an unconstrained supply of plant nutrients to enhance photosynthesis and yield growth for nonleguminous crops.[3] To increase the supply of nutrients, more ammonia should be synthesized and more phosphate and potash should be mined (Smil 1994, 273). Contrary to the belief of some analysts, plants do not discriminate between natural and mineral or chemical sources of nutrients. If not managed properly, nutrients from natural sources are no more environmentally friendly than those from manufactured fertilizer.

This paper analyzes the need for fertilizer, discusses past and future trends in fertilizer use and supply, and identifies the policies needed to promote environmentally sound growth in fertilizer use and supply. The paper also assesses environmental concerns and energy implications related to fertilizer use and suggests technical and policy-related measures to safeguard against possibly harmful environmental effects and to optimize energy use efficiency.

[1]In this paper, fertilizer includes nitrogen (N), phosphate (P_2O_5), and potash (K_2O) fertilizer products derived from mineral resources (for example, direct application of phosphate rock) or from chemical industry processes (urea, triple superphosphate, muriate of potash, and others).

[2]Environmental risks associated with fertilizer are mostly what Leisinger (1995) calls technology-transcending risks. That is, these risks are not inherent in fertilizer but are outcomes of the agroecological and socioeconomic circumstances in which fertilizers are applied (see Chapter 6 for details).

[3]Although legumes can fix their nitrogen directly from the atmosphere, they need adequate supplies of phosphorus (P) and potassium (K) to enhance their capacity for biological nitrogen fixation.

2. The Need for Fertilizer

Fertilizer Use and Food Security

World population increased from 3.0 billion in 1960 to 5.3 billion in 1990 and is projected to increase to 8.5 billion by 2025 (United Nations 1992). Such population growth is unprecedented in human history; the world added more people during this 30-year period than it did during the first 60 years of the twentieth century and the whole of the nineteenth century, and this trend is expected to continue. This unprecedented population growth has intensified pressures on the natural resource base—land, water, and air— to produce adequate food, fiber, and raw materials to meet the growing demand.

During 1961–90 cereal production nearly doubled, increasing from 876 million metric tons in 1961 to 1,947 million metric tons in 1990.[4] Although both the developed and the developing countries increased their cereal production, growth rates were higher in the developing countries, where cereal production increased from 396 million tons in 1961 to 1,035 million tons in 1990. In the developed countries, it increased from 481 million tons to 913 million tons during the same period, an annual compound growth rate of 3.3 percent in the former and 2.2 percent in the latter (FAO 1993). To meet the rising food demand in 2020, cereal production will have to increase to 1,260 million tons in the developed countries and 1,806 million tons in the developing countries (Rosegrant, Agcaoili, and Perez 1995).[5]

Past growth in cereal production was brought about by growth in both area cultivated and crop yields, but increases in yields played a dominant role, especially in developing countries where increased cereal yields contributed more than 80 percent to the growth in cereal production (Figure 1). Because the scope for expanding cultivable area is limited in most developing countries, especially in Asia, Central America, and North Africa, future increases in cereal production will mainly depend on increased crop yields, or what is known as "agricultural intensification" (Pinstrup-Andersen and Pandya-Lorch 1994).

Fertilizer contributes to increased crop production in several ways. First, by replenishing nutrients, it helps maintain and enhance soil fertility and thereby sustains crop production. Second, fertilizer enables adoption of high-yielding varieties (HYVs), which can increase cereal yields severalfold. Without a plentiful supply of nutrients through fertilizer and other associated inputs, HYVs cannot produce higher yields. Third, in the nutrient-poor soils of the tropics, fertilizer use can increase both crop yields and biomass (living matter above and below the ground); additional biomass can be used to augment the supply of organic matter (living and dead matter in the soil), which improves moisture retention and nutrient use efficiency and thereby contributes to increased crop yields. Consequently, cereal production and fertilizer use[6] are closely associated in the developing countries (Figure 2). Because future increases in cereal production are expected to come mostly from increases in crop yields (Rosegrant, Agcaoili, and Perez 1995; Mitchell and Ingco 1993; FAO 1993), fertilizer will remain an essential input in meeting the future food production requirements.

Fertilizer Use and Natural Resource Conservation

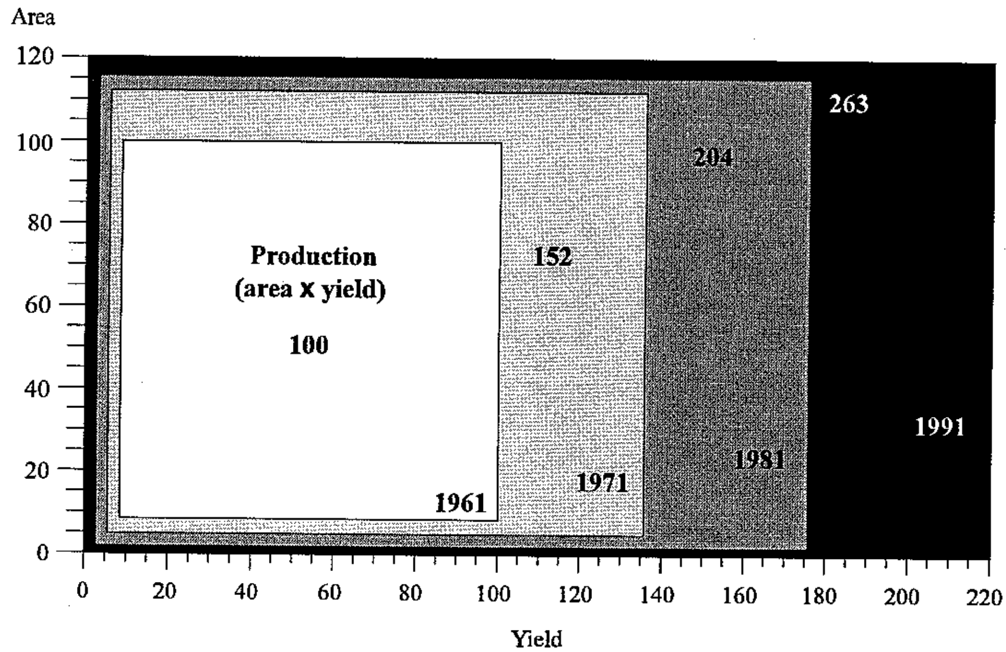
Degradation of the natural resource base is a major environmental threat in many developing countries,

[4]In this paper, all tons are metric tons.

[5]These data are for paddy rice rather than milled rice and refer to effective "market" demand based on income and population growth. To meet nutritional needs, the world will have to produce an additional 400 million tons of grains (Hazell 1994).

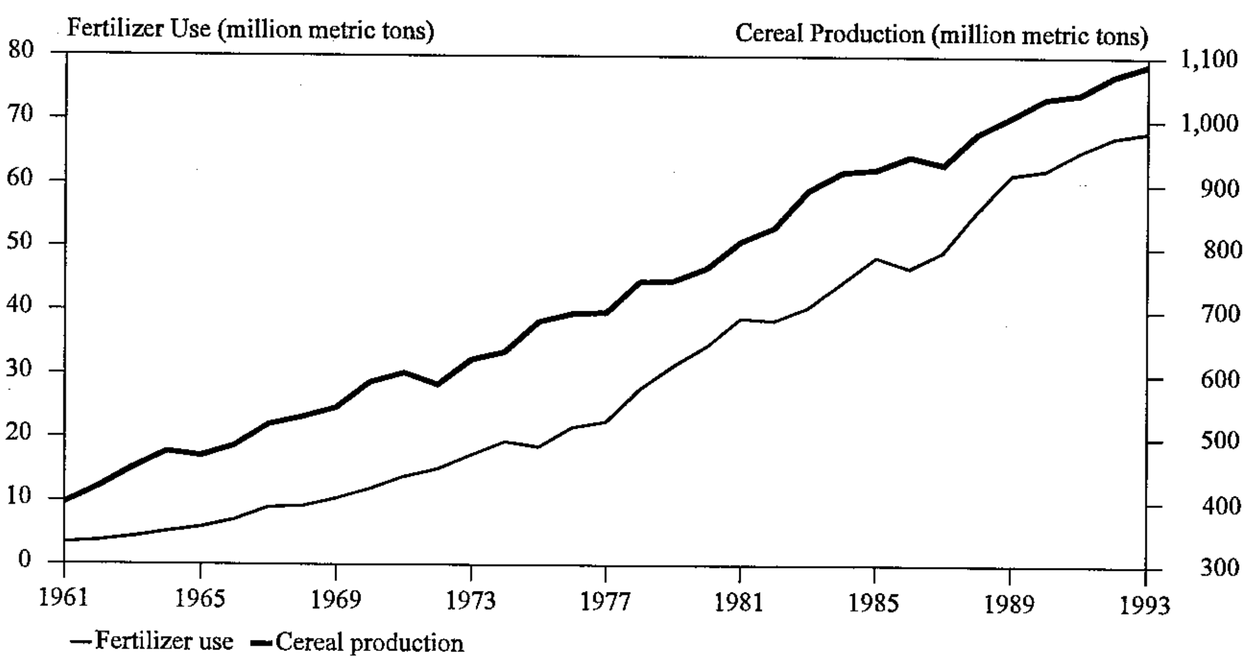
[6]In this paper, all fertilizer quantities are expressed in nutrient tons unless otherwise indicated.

Figure 1—Cereal production in developing countries, 1961–91



Source: Derived from data in FAO various years b.
Note: Index numbers: 1961 = 100.

Figure 2—Fertilizer use and cereal production in developing countries, 1961–93



Source: Derived from data in FAO various years a and b.
Note: Fertilizer quantities are in nutrient tons.

especially in Africa. Soil degradation, deforestation, and desertification are destroying land suitable for food production, reducing biodiversity, and having a negative effect on national incomes. Although no precise estimates are available at the global level, country-specific studies indicate that environmental degradation is reducing gross domestic product by 4 to 17 percent in the developing countries (Table 1). Globally, a study sponsored by the United Nations estimates that nearly 1.2 billion hectares of productive soils, an area the size of China and India combined, have been degraded by inappropriate agricultural practices, overgrazing, and deforestation (WRI, UNEP, and UNDP 1992). About three-fourths of this degradation has occurred in the developing countries. Soil degradation and deforestation continue to reduce productive capacity and biodiversity in many developing countries.

Although several factors have contributed to degradation of the soil, inadequate replenishment of removed nutrients and organic matter has reduced fertility and increased erosion rates. Between 1945 and 1990, nutrient depletion in Africa caused light degradation of 20.4 million hectares of land, moderate degradation of 18.8 million hectares, and severe degradation of 6.6 million hectares (Oldeman, Makkeling, and Sombroek 1990). For Asia, these estimates are 4.6, 9.0, and 1.0 million hectares, and for South America 24.5, 31.1, and 12.6 million hectares. In many countries of Sub-Saharan Africa, nutrient removal exceeds nutrient replenishment by a factor of 3 to 4, resulting in an annual loss of more than 8 million tons of nutrients (Stoorvogel and Smaling 1990). Traditionally, long fallows, 10 to 15 years in duration, were used to restore soil fertility, but increased population pressures have reduced the length of fallows in many African countries and have led to continuous cultivation in some countries. However, these reduced fallows have not been accompanied by compensatory measures to restore soil fertility. As fertility declines and soil becomes barren, resource-poor small farmers are forced to clear more forests to meet food needs. Because forest soil is fragile and nutrient-poor, it quickly becomes eroded and degraded, creating even more pressure to cut forests. Thus, a mutually reinforcing downward spiral of soil degradation, increased deforestation, and depletion of the natural resource base is initiated and perpetuated. This process ultimately leads to poverty, hunger and malnutrition, and further environmental degradation (Pinstrup-Andersen and Pandya-Lorch 1994).

Table 1—Estimated costs of environmental degradation in selected countries

Country	Nature of Environmental Degradation	Annual Cost as Percentage of GNP[a]
Burkina Faso, 1988	Crop, livestock, and fuelwood losses from land degradation	8.8
Costa Rica, 1989	Deforestation	7.7
Ethiopia, 1983	Deforestation	6.0–9.0
Indonesia, 1984	Soil erosion and deforestation	4.0
Madagascar, 1988	Land burning and erosion	5.0–15.0
Malawi, 1988	Soil erosion and deforestation	2.8–15.3
Nigeria, 1989	Soil degradation, deforestation, and others	17.4

Source: Pearce and Warford 1993.
[a]Gross national product.

Fertilizer use, along with other complementary measures, can help reverse the downward spiral of population pressure and environmental degradation in several ways. First, fertilizer can provide much-needed nutrients to the soil, thereby increasing crop yields and food production. Second, more crops mean more biomass to be plowed back to maintain the supply of organic matter and vegetative cover, thus enhancing moisture retention, nutrient use efficiency, and soil productivity. Used as a soil cover, crop residues also help to reduce soil erosion. Thus, well-managed fertilizer use can create a "win-win" situation by increasing food production and reducing soil degradation in nutrient-poor, fragile soils (Brady 1993). Third, by increasing crop production through fertilizer use in high-potential areas (those with better soils and favorable agroecological conditions), pressure to clear habitat-rich forests for crop production can be reduced. Fourth, a one-time, heavy application of phosphate rock and lime, followed by annual maintenance applications of fertilizer, can enhance and sustain the productivity of acid soil, which has considerable potential for food production in many developing countries (IBSRAM 1987). Finally, fertilizer can make an important contribution to intergenerational equity by preserving and sustaining the natural resource capital in the soils.

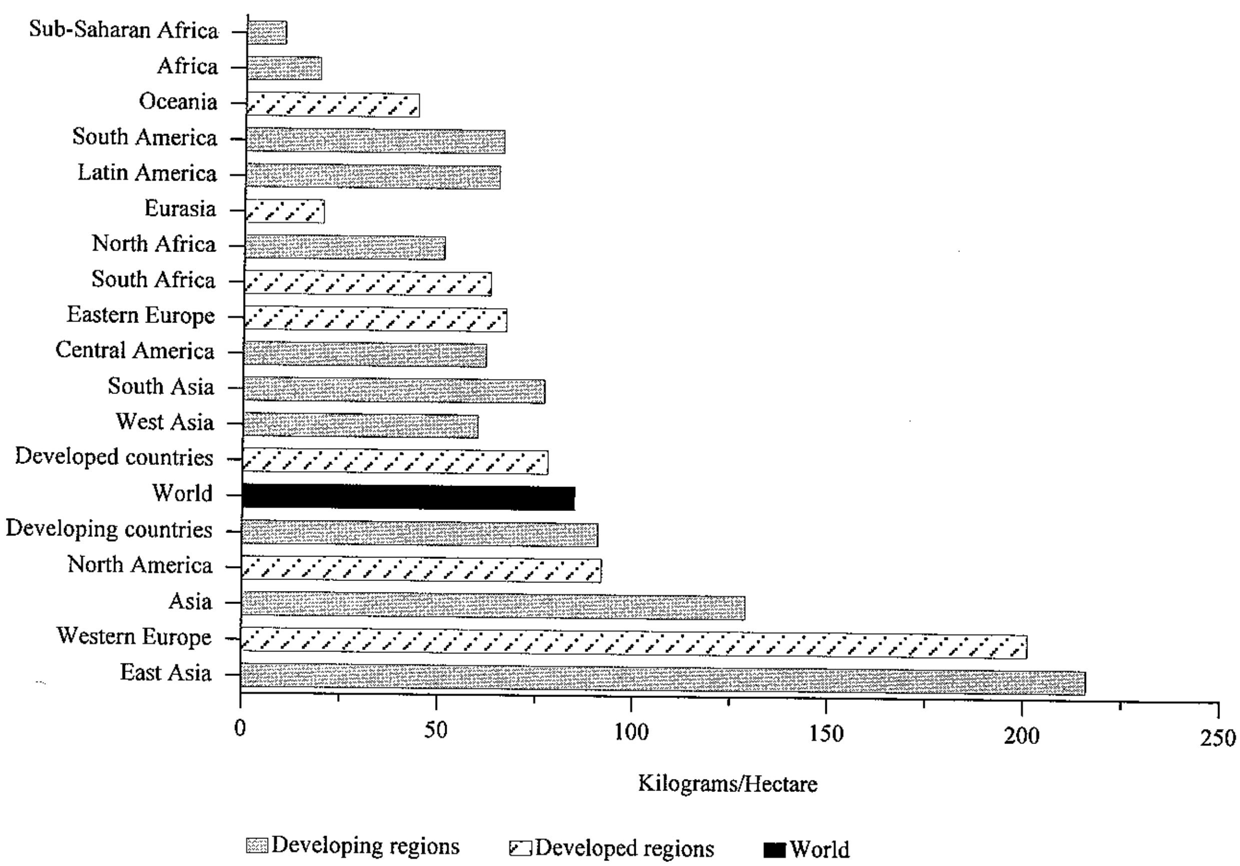
In addition, fertilizer can play an important role in enhancing biological nitrogen fixation. As indicated earlier, leguminous crops, through symbiosis with bacteria, can fix nitrogen directly from the atmosphere. However, their N-fixation capacity is greatly influenced by the availability of phosphorus (P) and potassium (K) in the soil and by soil pH (its acidity or alkalinity). Because many soils in the tropics are deficient in P and acidic, leguminous crops cannot fix the large amounts of N they need to produce higher yields. By increasing the supply of P through fertilizer application, the N-fixation capacity of these crops can be increased (Chien et al. 1993). Since leguminous crops are an important source of protein for the poor in developing countries, increasing their productivity through phosphate fertilizer could improve human nutrition and enhance soil productivity.

Global warming, resulting from the increased supply of CO_2 and other greenhouse gases in the atmosphere, has become an important concern. Although the magnitude and timing of its effects are still debated, policy measures to reduce global warming are widely discussed (Leggett 1990). Fertilizer use can help reduce global warming by enhancing sequestration of carbon in the organic matter of soils. Because plants absorb CO_2 in photosynthesis, higher crop yields and biomass accumulation obtained through the application of fertilizer results in absorption of more CO_2, a portion of which is held in soil organic matter. Increasing sequestration of carbon in soils may be one way to permanently remove large amounts of CO_2 from the atmosphere and reduce global warming (Sombroek 1994).

Need for a Pragmatic Approach

As has been argued, fertilizer is required for both food security and resource conservation. But the need for fertilizer will vary from one region to another and, within a region, from one country to another, because there is considerable diversity in fertilizer use patterns in the world. In 1994/95, fertilizer use per hectare varied from 10 kilograms per hectare in Sub-Saharan Africa to about 216 kilograms per hectare in East Asia (Figure 3). In the face of such diversity, strategies and policies designed to promote fertilizer use must be tailored to

Figure 3—Regional fertilizer use per hectare, 1994/95



Source: Derived from data in FAO various years a.
Note: See the Appendix for a classification of countries by region.

the specific needs of the country and region and remain pragmatic over time. This also mandates that policies and strategies be introduced to reduce fertilizer use in those countries where excessive use is causing damage to the environment.

In addition, fertilizer should become an integral part of an integrated nutrient management strategy in which the supply of nutrients from all sources—organic, inorganic, and biological—is optimized. Improving the supply of organic matter and soil amendments as well as fertilizer is essential because, without an adequate supply of organic matter, continuous use of fertilizer can lead to soil acidification and low crop yields (Tandon 1993).

Now there is *no* universal policy on fertilizer. The whole issue of the need for fertilizer must be considered in a pragmatic context over space and time.

3. Trends in Fertilizer Use, Production, and Trade

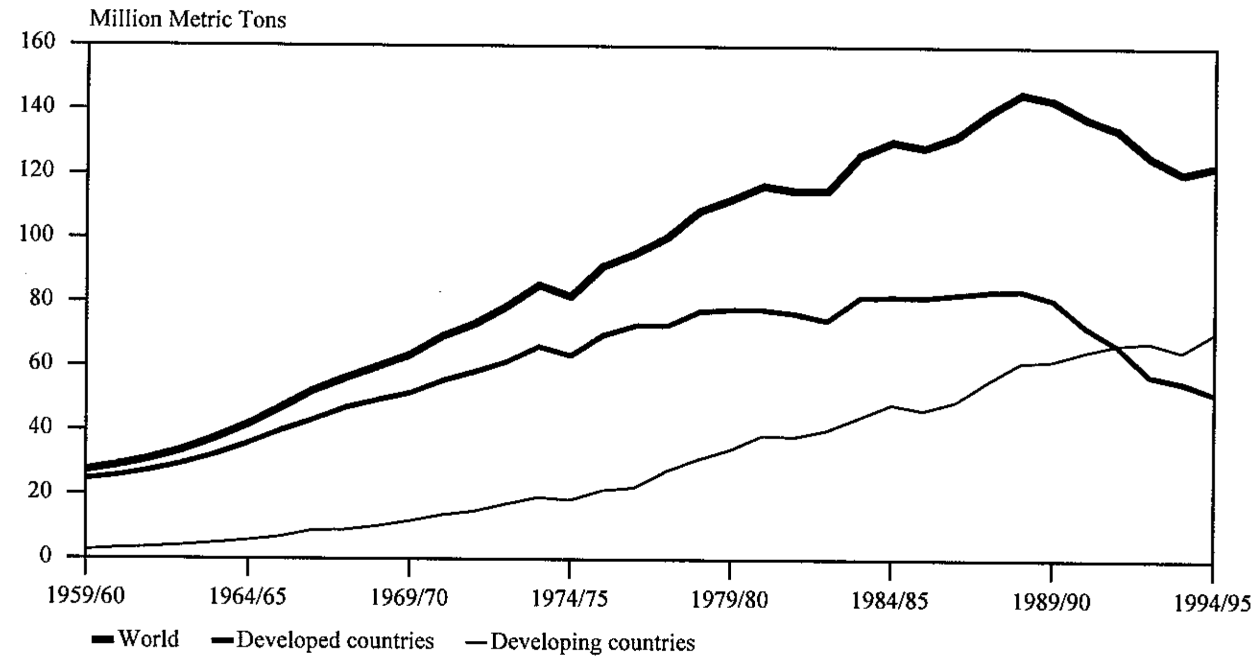
Fertilizer Use

Global Trends

Global fertilizer use increased from 27 million tons in 1959/60 to 146 million tons in 1988/89 and decreased thereafter to 121 million tons in 1993/94 (Figure 4). The declining trend in global fertilizer use since 1988/89 is the result of steep declines in fertilizer use in the reforming economies of Eastern Europe and Eurasia.[7] In 1994/95, global fertilizer use increased by 2 million tons. This is the first increase after 1988/89.

Fertilizer use increased in both the developed and the developing countries, although at a much higher rate in the latter. Slow growth in fertilizer use in the 1980s, followed by decline in the 1990s in the developed countries and steady growth in the developing countries, allowed the developing countries to surpass the developed countries in 1991/92. By 1994/95, the developing countries' share in global fertilizer use had increased to 58 percent, compared with 10 percent in 1959/60 and 31 percent in 1979/80. Asia, with a 50 percent share, was a bellwether for growth in fertilizer use in the developing countries.

Figure 4—World fertilizer use by economic region, 1959/60–1994/95



Source: FAO 1994 and 1996.
Note: Fertilizer quantities are in nutrient tons.

[7] Eurasia consists of the newly independent states of the former Soviet Union. See Appendix for details of the regional classification system used in this paper.

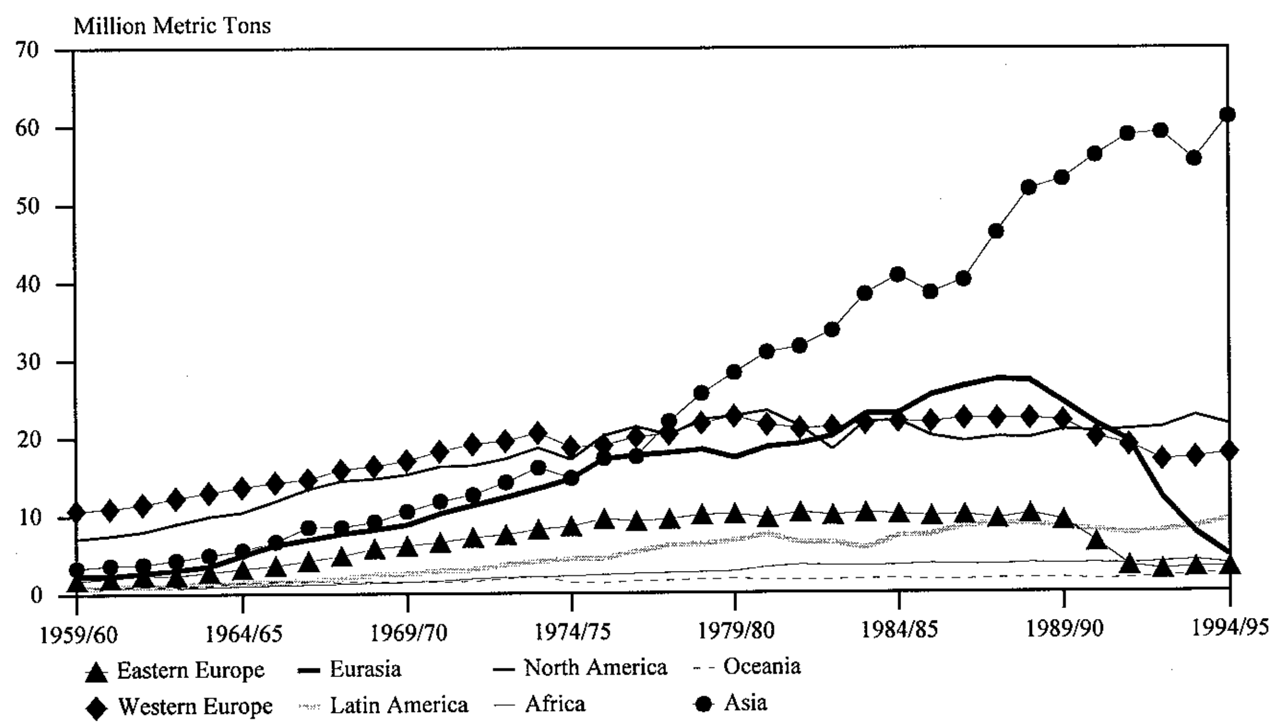
In 1959/60, the developing countries used less than 3 million tons of fertilizer nutrients, most of it concentrated on export crops. The launching of the Green Revolution in the mid-1960s in India and subsequently in other Asian countries accelerated the growth in fertilizer use. Fertilizer use in the developing countries increased to 11.9 million tons in 1969/70 and 34.5 million tons in 1979/80. The growing demand for foodgrains due to population and income growth and the limited scope for area expansion, especially in Asia, caused fertilizer use to nearly double in 15 years—rising from 34.5 million tons in 1979/80 to 71.2 million tons in 1994/95, an annual compound growth rate of 4.8 percent. In contrast, fertilizer use in the developed countries increased by only 0.8 percent a year—from 78 million tons in 1979/80 to 84 million tons in 1988/89, decreasing to 52 million tons in 1994/95. This slow growth followed by a decline was the result of grain surpluses, low crop prices, saturated markets, and, most important, the disintegration of economic and organizational arrangements in the fertilizer, agriculture, and industrial sectors of the reforming regions of Eastern Europe and Eurasia.

Global fertilizer use grew rapidly in the 1960s and the 1970s but slowly in the 1980s, decreasing from an annual growth rate of 8.9 percent in the 1960s to 5.6 percent in the 1970s and 2.8 percent in the 1980s. It could either decrease or increase marginally in the 1990s depending on whether the recovery in fertilizer use is slow or moderate in Eastern Europe and Eurasia (Bumb 1995). The relatively higher growth rates of the 1960s were from a small base in most regions, whereas the lower growth of the 1980s was mostly policy-induced due to grain surpluses in North America and Western Europe, economic reforms in the former centrally planned economies, and structural adjustment programs in the developing countries.

Regional Patterns

During the 1960s and 1970s, fertilizer use increased in all regions (Figure 5). During the 1980s and the early 1990s, growth performance varied considerably among regions. Fertilizer use decreased in North America, stagnated in Western Europe, Oceania, and Eastern Europe, increased modestly

Figure 5—Fertilizer use by geographic region, 1959/60–1994/95



Source: FAO 1994 and 1996.
Note: Fertilizer quantities are in nutrient tons.

(2–3 percent per year) in Africa and Latin America, and rose sharply (5–6 percent per year) in Eurasia and Asia in the 1980s. Efforts in Asia and Eurasia to achieve food self-sufficiency through increased fertilizer use were responsible for this high annual growth. During the 1988/89–1994/95 period, only Asia registered a significant increase in its fertilizer use; all other regions experienced either marginal increases or declines. In Eurasia and Eastern Europe, fertilizer use decreased by 83 percent and 69 percent, respectively.

It is clear from these data that, during the 1979/80–1994/95 period, Asia dominated regional performance. In Asia, fertilizer use increased by 32.8 million tons—from 28.3 million tons in 1979/80 to 61.1 million tons in 1994/95, making Asia not only the leader in fertilizer use in the developing world but also in the world as a whole. Asia accounted for 50 percent of global fertilizer use and 86 percent of the developing world's fertilizer use in 1994/95, largely due to a stable and conducive policy environment in most Asian countries, including India, China, and Indonesia. All three subregions of Asia performed well, but East Asia had the greatest absolute growth (Table 2).

Table 2—Fertilizer use in Africa, Latin America, and Asia, 1959/60–1994/95

Region	1959/60	1969/70	1979/80	1988/89	1994/95
	(million metric tons)				
Africa	0.5	1.4	2.8	3.7	3.5
North	0.2	0.6	1.1	1.7	1.4
Sub-Saharan	0.1	0.4	0.7	1.2	1.3
South	0.2	0.5	1.0	0.8	0.8
Latin America	0.7	2.5	6.7	8.7	9.3
Central	0.3	1.3	2.1	3.0	2.4
South	0.4	1.2	4.7	5.8	6.9
Asia	3.3	10.6	28.3	51.9	61.1
East	2.8	7.3	19.1	34.0	40.0
South	0.4	2.6	7.0	14.0	17.3
West	0.1	0.7	2.2	3.9	3.8

Source: FAO 1994 and 1996.

To promote rapid growth in fertilizer use, Asian countries introduced several programs and policies affecting both fertilizer demand and supply. On the supply side, they invested heavily in fertilizer production and imports and in marketing and distribution infrastructure, maintained exchange rate stability and allocated sufficient foreign exchange to ensure an adequate and timely supply of fertilizer. On the demand side, fertilizer and credit subsidies and minimum crop price support programs were successfully implemented to provide incentives for fertilizer use. The crop and fertilizer pricing policy was managed in such a way that farmers in most Asian countries were not required to pay more than 2 kilograms of milled rice for 1 kilogram of N fertilizer (Bumb 1989). The development of irrigation infrastructure was equally important in promoting growth in fertilizer use. Moreover, most Asian countries did not subject their economies to the "shock therapy" of structural adjustment programs and economic reforms, which led to policy instability and institutional and organizational discontinuity in many countries.

In contrast to Asia's steady growth, Latin America experienced wide fluctuations and modest growth in fertilizer use due to an unstable policy environment. Debt crises, rapid devaluation, subsidy removal, inadequate credit support, and declining crop prices for agricultural exports were the major factors responsible. Inadequate fertilizer supply from the former Soviet Union to Cuba also had an adverse effect, especially in Central America in the early 1990s.

In Sub-Saharan Africa, fertilizer use increased in modest amounts, rising from 0.7 million tons in 1979/80 to 1.5 million tons in 1992/93, then decreasing to 1.2 million tons in 1994/95. At about 10 kilograms per hectare, fertilizer use intensity in Sub-Saharan Africa was the lowest in the developing world, stagnating at about 1 million tons of nutrients between 1981/82 and 1986/87 (Bumb 1995). Foreign exchange shortages, low crop prices, and inadequate institutional and physical infrastructure have kept fertilizer use low. Policy instability resulting from structural adjustment programs also had an adverse effect on fertilizer use in several countries, including Cameroon, Ghana, and Zambia. Unlike Asian countries, most countries in Sub-Saharan Africa have not shown a high degree of political commitment to promote growth in fertilizer use, as reflected in their excessive dependence on fertilizer aid to meet domestic fertilizer requirements. More than half of the countries in Sub-Saharan Africa depend on fertilizer aid to meet all of their fertilizer needs (Table 3). Such excessive dependence on fertilizer aid introduces uncertainty in fertilizer use because most fertilizer aid commitments are short-term and ad hoc (Bumb 1989).

Fertilizer Use by Nutrients

World nitrogen (N) fertilizer use increased from 9.5 million tons in 1959/60 to 57.2 million tons in

Table 3—Distribution of countries in Sub-Saharan Africa by the ratio of fertilizer aid to fertilizer imports, 1985–90

Ratio	1985	1987	1990
(percent)		(number of countries)	
0	7	8	6
1–20	3	4	3
20–50	2	1	2
50–80	3	5	7
80–99	2	2	0
100	23	20	22
Total number of countries	40	40	40

Source: FERTECON 1993.

1979/80 to 79.6 million tons in 1988/89 (Table 4). During the same period, phosphate (P_2O_5) use increased from about 10 million tons to 38 million tons and potash (K_2O) use from 8 million tons to 28 million tons. After 1988/89, global use of all three nutrients decreased.

Of the 71 million tons of fertilizer nutrients used by the developing countries in 1994/95, N fertilizers accounted for 45 million tons, or 64 percent, and P_2O_5 and K_2O for 18 million tons (25 percent) and 8 million tons (11 percent), respectively. Because HYVs responded quickly and decisively to N, having a visible effect on crop production, use of N was popular with farmers. Domestic availability and a favorable pricing environment also contributed to this process. The availability of P and K in the soil at the lower rates of N application made it unnecessary to use high levels of P_2O_5 and K_2O. However, N's dominance in total fertilizer use indicates that developing countries are using fertilizer in an unbalanced manner (Table 5).[8] In order to improve fertilizer use efficiency and minimize adverse environmental impacts associated with nitrogen use, nutrient balance should be improved by promoting P_2O_5 and K_2O fertilizer use.

Table 4—World fertilizer consumption by nutrients, 1959/60–1994/95

Year	1959/60	1969/70	1979/80	1988/89	1994/95
			(million metric tons)		
Developed countries					
N	7.9	20.9	34.7	39.8	28.3
P_2O_5	9.0	16.7	22.9	22.9	12.0
K_2O	7.8	13.9	20.4	21.4	11.7
Total	24.7	51.6	78.0	84.1	52.0
Developing countries					
N	1.7	7.5	22.5	39.8	45.3
P_2O_5	0.8	3.1	8.3	15.1	17.7
K_2O	0.3	1.3	3.6	6.6	8.2
Total	2.7	11.8	34.5	61.5	71.2
World					
N	9.5	28.5	57.2	79.6	73.6
P_2O_5	9.7	19.8	31.2	38.0	29.6
K_2O	8.1	15.2	24.1	28.0	20.0
Total	27.4	63.5	112.5	145.6	123.2

Source: FAO 1994 and 1996.
Notes: Totals may not add due to rounding. N is nitrogen, P_2O_5 is phosphate, and K_2O is potash.

Fertilizer Use by Crops

Data on fertilizer use by crop are not readily available because many countries do not collect these

Table 5—Ratio of nitrogen to phosphate and to potash in selected countries in Africa, Asia, and Latin America, 1994/95

Region/Country	$N:P_2O:K_2O$
Africa	
Cameroon	1.0:0.33:0.66
Ghana	1.0:0.80:0.20
Egypt	1.0:0.14:0.03
Kenya	1.0:1.20:0.02
Nigeria	1.0:0.62:0.49
Zambia	1.0:0.34:0.21
Asia	
Bangladesh	1.0:0.19:0.12
China	1.0:0.38:0.12
India	1.0:0.31:0.11
Indonesia	1.0:0.30:0.20
Pakistan	1.0:0.25:0.01
Turkey	1.0:0.44:0.05
Latin America	
Argentina	1.0:0.67:0.12
Brazil	1.0:1.48:1.54
Colombia	1.0:0.44:0.57
Cuba	1.0:0.18:0.54
Mexico	1.0:0.31:0.08
Venezuela	1.0:0.41:0.34

Source: Derived from FAO 1996 data.

[8] Although balanced fertilizer use varies from region to region, and from one crop to another in the same region, a $N:P_2O_5:K_2O$ ratio of 2:1:1 is generally considered desirable.

statistics on a regular basis. Recently, the International Fertilizer Industry Association (IFA), the International Fertilizer Development Center (IFDC), and the Food and Agriculture Organization of the United Nations (FAO) (1994) collaborated to estimate such data based on official and unofficial information. Because they are estimated, these data indicate the general magnitude rather than exact measurement of fertilizer use by crops. This information was used to calculate the share of cereals, roots and tubers, legumes, and other crops in total fertilizer use at global and regional levels (Table 6). The data included in the IFA/IFDC/FAO 1994 estimates account for a significant proportion but not all of the total fertilizer use in the countries included in the study. Hence the percentage shares reported in Table 6 are based on the total fertilizer use on the included crops for 72 countries, covering about 80 percent of global fertilizer use.

During 1988–91, about 59 percent of global fertilizer use was devoted to cereals. Roots and tubers and legumes accounted for 5 percent and 4 percent, respectively. Thus, more than two-thirds of fertilizer was used on food crops. In the developed countries cereals accounted for about 53 percent and in the developing countries about 66 percent. At the regional level, the share of cereals ranged from 34 percent in South America to 72 percent in South Asia. The contrast between South Asia and South America is striking; South Asia concentrated most of its fertilizer use on cereals, whereas South America focused on noncereal export crops such as soybeans, coffee, cocoa, cotton, sugarcane, and bananas. South Asia's need to produce enough food to feed more than one-fifth of the world population (1.2 billion in 1992) on limited cultivable land naturally resulted in a heavy concentration of fertilizer on cereals. Sub-Saharan Africa's relatively large share going to cereals is a result of a heavy concentration of use in Nigeria, which accounted for about 55 percent of the fertilizer use on cereals in the region. In other countries, such as Côte d'Ivoire, Madagascar, and Togo, cereals received from 17 to 34 percent of fertilizer.

In most countries, cereals accounted for the largest share of total fertilizer use. China, India, Mexico, Nigeria, and the United States devoted more than 65 percent of the fertilizer used to cereals; Bangladesh, Indonesia, Saudi Arabia, and Vietnam devoted more than 80 percent. Unlike other countries that concentrate fertilizer use on cereals to promote food self-sufficiency, the United States used fertilizer heavily on cereals because of their importance as exports. In

Table 6—Relative shares of fertilizer use by region and crop, 1988–91

Region	Cereals	Roots and Tubers	Legumes[a]	Other Crops[b]	Hay and Forage
			(percent)		
North America	70.3	1.4	6.1	9.6	12.6
Western Europe	44.3	3.3	1.3	21.2	29.9
Eastern Europe	41.8	8.3	1.2	18.2	30.5
Eurasia	47.1	8.6	0.4	11.5	32.4
Oceania	43.8	1.4	3.5	22.5	28.7
Africa	59.2	4.1	3.3	29.6	3.8
North	58.4	4.2	3.9	33.5	. . .
Sub-Saharan	63.8	5.2	3.5	27.2	0.3
South	55.2	2.7	2.0	26.5	13.6
Latin America	41.4	4.1	12.1	40.3	2.1
Central	57.6	2.0	1.6	36.8	2.0
South	33.8	5.0	17.1	42.0	2.1
Asia	68.7	5.5	3.5	21.5	0.8
East	68.3	7.8	3.9	19.1	0.9
South	71.7	1.3	2.9	24.1	. . .
West	58.1	2.9	3.1	32.2	3.7
World	59.3	4.6	3.7	19.8	12.6
Developed countries	53.3	4.0	2.8	15.9	24.0
Developing countries	65.8	5.3	4.6	23.8	0.5

Source: IFA/IFDC/FAO 1994.
Note: The leaders (. . .) indicate a negligible amount.
[a]Includes pulses and soybeans.
[b]Includes fruits and vegetables, oilseeds, tree crops, sugarcane/sugarbeet, cotton, tobacco, and others.

1990/91, the United States exported 82.1 million tons of grain, accounting for about 44 percent of the global grain exports (FAO 1992, 39).

Because cereals contribute the largest share to food intake in many countries, increased cereal production is essential to meet the food security challenge. Where the availability of cultivable land is limited, especially in Asia, many countries have been forced to adopt yield-increasing technologies that require heavy fertilizer use. Because HYVs of rice, maize, and wheat are fertilizer intensive, their adoption increases the amount of fertilizer used. Although cereals will continue to dominate fertilizer use in the future, increasing agricultural diversification toward fruits, vegetables, and commercial crops may reduce cereals' share slightly in the developing countries.

In addition to cereals, other crops such as roots and tubers, pulses, soybeans, oilseeds, fruits and vegetables, beverages, and sugarcane and beets, which contribute directly and indirectly to human consumption, account for a significant proportion of fertilizer use in both developed and developing countries. If the share of these crops in fertilizer use is added to that of cereals, the food sector may easily account for about 80 percent of the global fertilizer use and more than 90 percent of the fertilizer use in developing countries. The overwhelming importance of fertilizers in food production mandates that the growth in fertilizer use must be sustained to meet the food security challenge to 2020. And efforts should be made to develop a reliable database on fertilizer use by crops in various countries so that plausible policies and technologies can be developed.

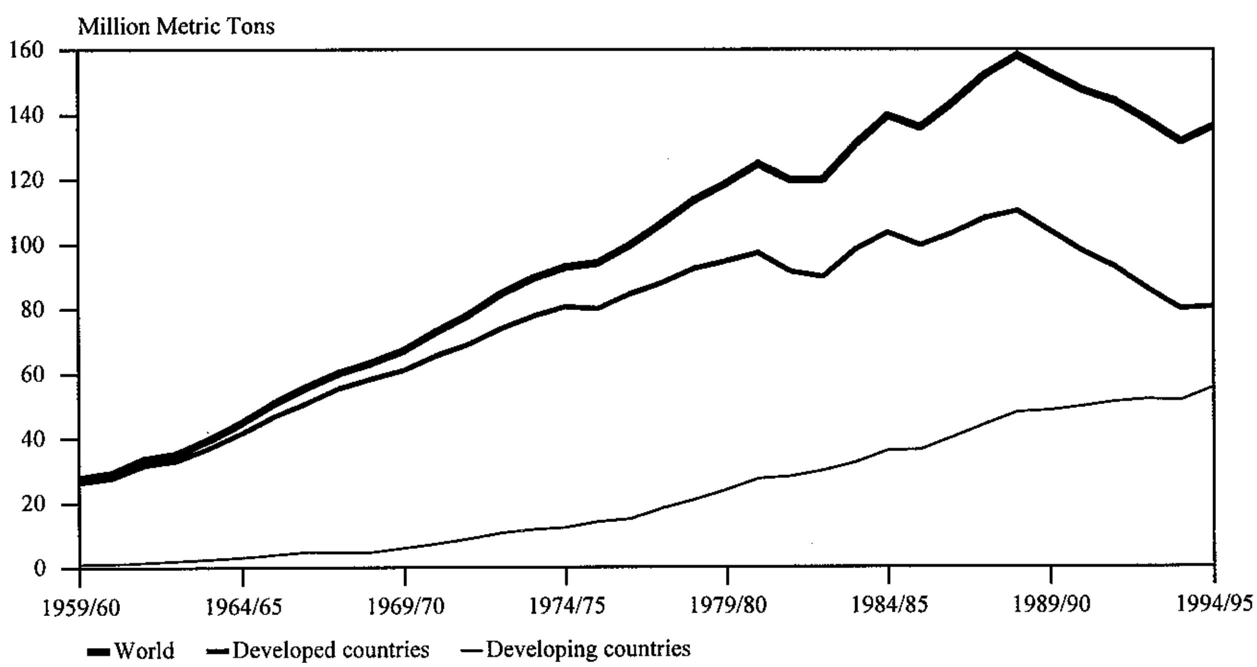
Fertilizer Production

Global Trends

Rapid growth in fertilizer use in the 1960s and the 1970s also stimulated rapid growth in fertilizer production. Global fertilizer production increased from about 28 million tons in 1959/60 to 119 million tons in 1979/80 (Figure 6). During the 1980s, it increased at a slower rate until it reached 158 million tons in 1988/89. In the following five years, it decreased by about 26 million tons primarily due to economic disintegration in Eastern Europe and Eurasia. In 1994/95, it increased by 5 million tons.

Until the late 1980s, fertilizer production increased in both the developed and the developing

Figure 6—World fertilizer production by economic region, 1959/60–1994/95



Source: FAO 1994 and 1996.
Note: Fertilizer quantities are in nutrient tons.

countries. Thereafter, it decreased rapidly in the developed countries due to the fall in production in the former centrally planned economies. In the developing countries, fertilizer production increased from about 1 million tons in 1959/60 to 24 million tons in 1979/80. In the next 15 years, it more than doubled to reach 56 million tons in 1994/95. Consequently, the developing countries' share in global production increased from 2 percent in 1959/60 to 20 percent in 1979/80 and 41 percent in 1994/95. Although the developing countries' share has increased significantly during the last 35 years, their level of production is lower than that of the developed countries. This reflects the limited resource base (raw materials, especially for P_2O_5 and K_2O production) in developing countries and the inadequate foreign exchange available to import equipment and raw materials.

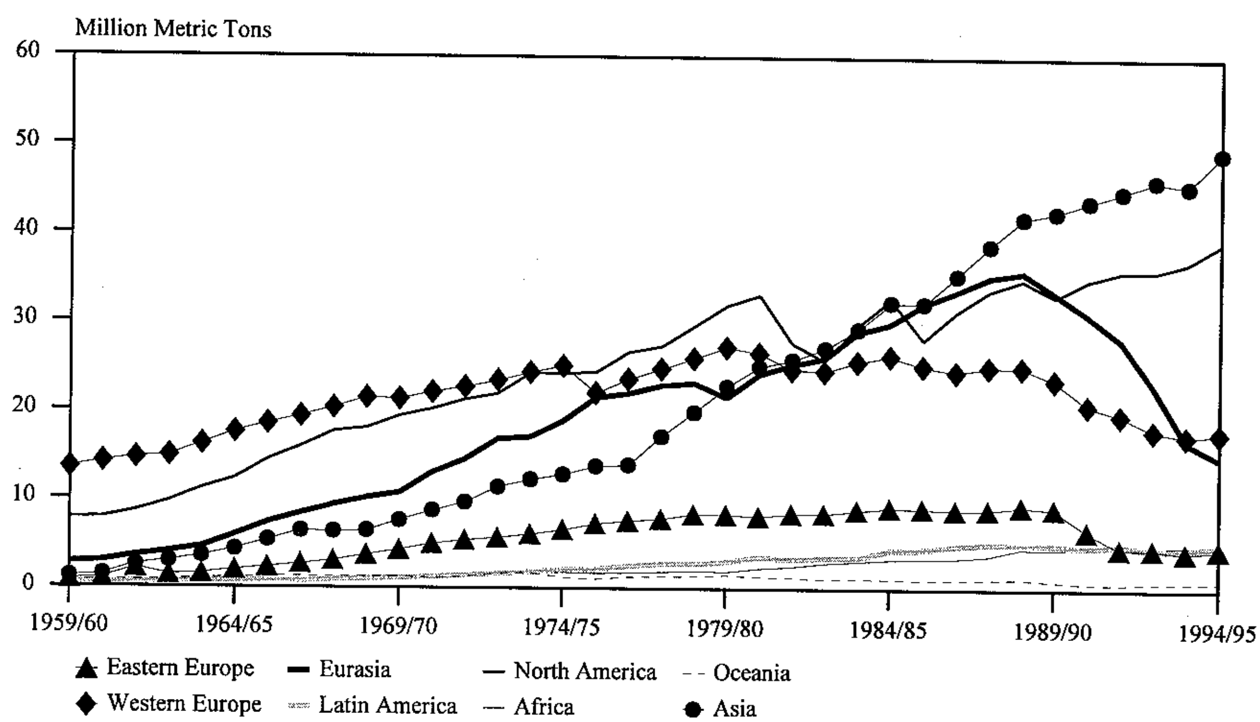
Regional Patterns

Like fertilizer use, fertilizer production increased in all regions during the 1960s and the 1970s (Figure 7). By 1979/80, fertilizer production had reached 32 million tons in North America, 27 million tons in Western Europe, 22 million tons in Eurasia, and 23 million tons in Asia. Taken together, these four regions accounted for more than 87 percent of the global fertilizer production in 1979/80. During the 1980s, all regions except Western Europe and Oceania registered growth in fertilizer production; Asia and Eurasia had the highest absolute growth of 19 and 15 million tons, respectively. Africa also increased its production significantly.

The performance of the early 1990s was in striking contrast to that of the 1980s. Eurasia, Western Europe, Latin America, and Eastern Europe decreased their fertilizer production, whereas Asia and North America registered 18 percent and 12 percent increases, respectively, during the 1988/89–1994/95 period.

In Asia, fertilizer production increased rapidly during the 1970–95 period. By 1994/95, Asia accounted for 36 percent of global fertilizer production and 84 percent of fertilizer production in developing countries. The need to ensure an adequate and

Figure 7—World fertilizer production by geographic region, 1959/60–1994/95



Source: FAO 1994 and 1996.
Note: Fertilizer quantities are in nutrient tons.

timely supply of fertilizer, especially N fertilizer, for adoption and spread of the Green Revolution technologies motivated many Asian countries to invest in fertilizer production facilities. The availability of natural gas also facilitated this expansion. Because fertilizer investments are foreign exchange intensive, World Bank support for constructing fertilizer plants provided added stimulus.[9] The World Bank financed several fertilizer projects in Asian countries including Bangladesh, China, India, Indonesia, and Turkey (World Bank 1989). In addition, West Asian countries that are rich in oil and natural gas also invested heavily in fertilizer production for export. Consequently, fertilizer production increased from 1.2 million tons in 1959/60 to 22.8 million tons in 1979/80 and 49.3 million tons in 1994/95. All three subregions experienced rapid growth, but East Asia accounted for 58 percent of the fertilizer production in Asia in 1994/95 (Table 7).

Fertilizer production also increased rapidly in Latin America until the early 1980s but grew slowly thereafter. Unstable fertilizer demand and foreign exchange shortages due to debt crises and declining export revenues have had an adverse impact on fertilizer production in this region. Declining fertilizer prices also affected fertilizer production, especially in Central America where a large proportion of N production is geared to exports.

Table 7—Fertilizer production in Africa, Latin America, and Asia, 1959/60–1994/95

Region	1959/60	1969/70	1979/80	1988/89	1994/95
	(million metric tons)				
Africa	0.3	1.2	2.0	4.7	4.8
North	0.2	0.5	0.9	3.3	3.6
Sub-Saharan	a	0.1	0.2	0.5	0.4
South	0.1	0.5	0.9	0.8	0.8
Latin America	0.4	1.2	3.1	5.1	5.0
Central	a	0.7	1.1	2.2	1.9
South	0.4	0.5	2.0	2.9	3.1
Asia	1.2	7.6	22.8	41.9	49.3
East	0.9	5.8	16.8	24.4	28.8
South	0.2	1.1	3.8	11.1	13.3
West	0.1	0.7	2.8	6.4	7.1

Source: FAO 1994 and 1996.
[a]Less than 50,000 nutrient tons.

Fertilizer production in Africa was concentrated mostly in North Africa, which accounted for 74 percent of the production in 1994/95. In Sub-Saharan Africa, only Nigeria had a large-scale ammonia-urea plant producing about 270,000 tons of N. Senegal's capacity for P_2O_5 production was large. A few other countries, such as Zambia and Zimbabwe, produced modest quantities in small plants. In 1994/95, Sub-Saharan Africa produced 0.4 million tons of nutrients—less than 1 percent of fertilizer production in the developing countries and 0.3 percent of global production. North Africa produced nearly 3.6 million tons of nutrients in the same year. Morocco and Tunisia are major producers of P_2O_5 fertilizers and Egypt and Libya of N fertilizers. A large proportion of P_2O_5 from this region is exported to other countries.

Many countries in Sub-Saharan Africa are rich in phosphate rock (PR)—a crucial raw material for producing P_2O_5 fertilizers. However, because of low domestic demand and global surpluses leading to unremunerative prices, these rock deposits have not been developed. Nevertheless, they could serve as a good source of phosphorus if PR were applied as a soil amendment to African soils (World Bank 1994). An improved policy environment and greater political commitment as well as donor support are needed to tap this resource.

Fertilizer Production by Nutrients

Like fertilizer use, fertilizer production is dominated by N. In 1994/95, the world produced about 80 million tons of N, 33 million tons of P_2O_5, and 23 million tons of K_2O. Of this, the developing countries produced about 40 million tons of N, 14 million tons of P_2O_5, and 1 million tons of K_2O (Table 8). Thus, nitrogen production accounted for more than 72 percent of the total fertilizer production in the developing countries.

At the global level, N, P_2O_5, and K_2O production increased until 1988/89 and decreased thereafter. In the developing countries, N production increased from 0.7 million tons in 1959/60 to about 40 million tons in 1994/95. Limited availability of potash ores and phosphate rock prevented production of P_2O_5 and K_2O from growing rapidly. Widespread availability of natural gas and strong demand

[9] Although the World Bank accounted for only a small share of the total fertilizer investment in the developing countries, its presence acted as a catalyst to generate additional domestic investment in the fertilizer sector.

Table 8—Fertilizer production by nutrients, 1959/60–1994/95

Region/Type of Fertilizer	1959/60	1969/70	1979/80	1988/89	1994/95
	(million metric tons)				
Developed countries					
N	8.5	26.4	41.9	51.7	40.1
P_2O_5	9.3	18.2	27.1	28.4	18.8
K_2O	8.7	16.6	25.8	30.3	21.9
Total	26.5	61.1	94.8	110.3	80.8
Developing countries					
N	0.7	3.9	17.7	34.1	40.3
P_2O_5	0.4	2.2	6.2	13.0	14.0
K_2O	[a]	0.1	0.1	0.9	1.3
Total	1.2	6.1	24.0	48.0	55.6
World					
N	9.2	30.2	59.6	85.7	80.4
P_2O_5	9.8	20.4	33.3	41.4	32.8
K_2O	8.7	16.7	25.9	31.2	23.2
Total	27.7	67.2	118.7	158.3	136.4

Source: FAO 1994 and 1996.
Note: Totals may not add up due to rounding.
[a]Less than 50,000 tons.

facilitated the rapid growth in N production. The limited production base for P_2O_5 and K_2O made many developing countries dependent on fertilizer imports to meet domestic requirements. However, due to foreign exchange shortages, many developing countries have restricted fertilizer imports and ended up with unbalanced nutrient use.

Fertilizer Trade

Global Trends

Global fertilizer imports[10] increased almost 7 percent per year, rising from about 7 million tons in 1959/60 to 49 million tons in 1988/89 and stagnating thereafter until 1993/94 (Table 9). In 1994/95, imports increased to 52.4 million tons. The share of imports in fertilizer consumption also increased from 25 percent in 1959/60 to 33 percent in 1988/89 and 43 percent in 1994/95. Likewise, the ratio of exports to production increased from 26 percent in 1959/60 to 38 percent in 1994/95. These trends suggest that fertilizer trade has become an important source of fertilizer supply in several countries. Because of low global fertilizer prices in the 1980s, many developing countries, including India and China, have relied more on imports to meet their domestic fertilizer requirements and less on investments in capacity building for achieving fertilizer self-sufficiency. Increased exports from the reforming regions have also contributed to this process.

Although fertilizer production increased rapidly in the developing countries, it was not sufficient to meet the growing demand. Consequently, fertilizer trade also increased (Figure 8). Net fertilizer imports (imports minus exports) increased from about 1 million tons in 1959/60 to 11 million tons in 1979/80 and 17 million tons in 1994/95. In gross terms, fertilizer imports increased from 2.5 million tons in 1959/60 to 25.0 million tons in 1994/95, whereas fertilizer exports increased from 0.3 million tons to 8.9 million tons during the same period. At the same time, the availability of natural gas and phosphate rock, especially in West Asia and North Africa, promoted growth in fertilizer exports.

Regional Trends

Because regional data on net imports in Table 10 exclude intraregional trade among countries within

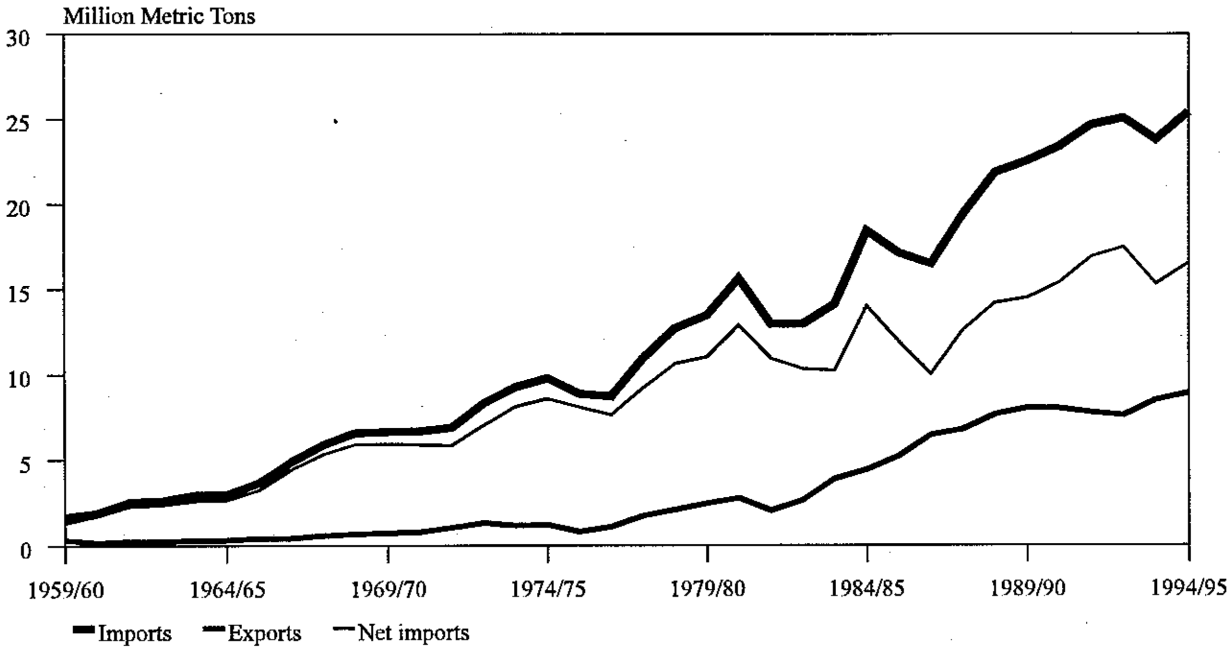
Table 9—World imports and exports of fertilizer, 1959/60–1994/95

Fertilizer	1959/60	1969/70	1979/80	1988/89	1994/95
	(million metric tons)				
Imports					
N	2.3	6.5	12.6	19.8	22.4
P_2O_5	1.0	2.7	5.8	9.6	11.0
K_2O	3.4	8.9	15.5	19.1	19.0
Total	6.8	18.0	34.0	48.5	52.4[a]
Ratio of imports to fertilizer use (percent)	24.8	28.3	30.1	33.3	42.5
Exports					
N	2.7	6.5	11.9	19.5	21.7
P_2O_5	1.2	2.7	6.8	10.3	12.3
K_2O	3.4	9.0	15.6	18.5	18.4
Total	7.3	18.3	34.4	48.3	52.4
Ratio of Exports to Production (percent)	26.4	30.0	29.0	30.5	38.4

Source: Derived from FAO 1994 and 1996 data.
Note: Totals may not add due to rounding.
[a]During 1989/90–1993/94, fertilizer imports remained stagnant at 49 million metric tons.

[10]In theory, at the global level, fertilizer imports should be identical to fertilizer exports. In practice, the two quantities are generally not identical due to in-transit shipments, losses, and reporting errors.

Figure 8—Fertilizer imports and exports by developing countries, 1959/60–1994/95



Source: FAO 1994 and 1996.
Note: Fertilizer quantities are in nutrient tons.

a region, they indicate whether a particular region is deficit or surplus in fertilizer nutrients. On this basis, in 1994/95 North America, Eurasia, Eastern Europe, and Africa were net exporters and Asia, Latin America, Oceania, and Western Europe were net importers. Net exporters within Africa and Asia were North Africa and West Asia.

Table 10—Net fertilizer imports by region, 1959/60–1994/95

Region	1959/60	1969/70	1979/80	1988/89	1994/95
	(million metric tons)				
North America	(0.2)	(3.0)	(6.7)	(8.1)	(9.2)
Western Europe	(2.5)	(3.2)	(3.0)	(1.2)	2.3
Oceania	0.1	0.3	0.3	0.7	1.5
Eastern Europe	0.9	1.8	1.5	1.2	(1.5)
Eurasia	(0.2)	(1.0)	(3.0)	(6.0)	(9.1)
Africa	0.2	0.4	0.9	(0.8)	(1.0)
North	0.1	[a]	0.2	1.5	(2.1)
Sub-Saharan	0.1	0.3	0.6	0.8	1.0
South	0.1	0.1	0.1	(0.0)	[a]
Latin America	0.1	1.4	3.6	3.8	4.8
Central	0.1	0.7	1.0	0.8	0.7
South	(0.1)	0.7	2.7	2.9	4.2
Asia	1.2	3.1	6.0	10.6	12.2
East	0.9	1.7	3.2	10.5	11.3
South	0.3	1.4	3.1	2.5	4.1
West	[a]	[a]	(0.4)	(2.4)	(3.2)

Source: Derived from FAO 1994 and 1996 data.
Notes: Net is imports minus exports. Numbers in parentheses are net exports. Totals may not add up due to rounding.
[a]Amount less than 50,000 tons.

Over time, many regions have improved or switched their positions. North America improved its position, but Western Europe reversed its position from a net exporter until 1988/89 to a net importer in 1994/95. Oceania's net imports increased from 0.1 million tons in 1959/60 to 1.5 million tons in 1994/95, as the result of reduced domestic production.

Eurasia also improved its position as a net exporter by increasing net exports from 0.2 million tons in 1959/60 to 6.0 million tons in 1988/89. A drastic fall in domestic fertilizer use has further strengthened its position; by 1994/95, Eurasia was exporting 9.1 million tons. Eastern Europe's net imports decreased between 1969/70 and 1988/89, but, due to reduced domestic use, it became a net exporter by 1994/95.

Among the developing regions, both Asia and Latin America remained net importers, whereas Africa changed its position. In 1979/80, Africa was a net importer of about 0.9 million tons, but by 1994/95, it had become a net exporter of 1 million tons. North Africa alone contributed to this switchover in Africa's trading position; exports of phosphate fertilizer from Morocco, Jordan, and Tunisia dominated African exports. Sub-Saharan Africa remained a net importer. Both South America and Central America were net importers, although Central America's dependence on fertilizer imports was modest.

East and South Asia also remained net importers, with net fertilizer imports increasing nearly 11-fold in East Asia during 1959/60–1994/95. The desire to achieve food security through increased fertilizer use was the main force behind this spectacular increase in net imports of fertilizer nutrients in East Asia. West Asia, on the other hand, increased its net exports from 0.4 million tons in 1979/80 to 2.4 million tons in 1988/89. The availability of cheap natural gas encouraged investment in production capacity for exports in West Asia. After 1988/89, its exports decreased until 1993/94 because relatively cheaper exports were available from the reforming regions of Eastern Europe and Eurasia. In 1994/95, exports from this region increased to 3.2 million tons.

South America, South Asia, East Asia, and Sub-Saharan Africa are likely to continue to be large net importers. Lack of raw materials for production of P_2O_5 and K_2O make these regions dependent on imports, although the small size of the market, foreign exchange shortages, and a nonconducive policy environment have kept fertilizer imports low in Sub-Saharan Africa.

Asia in general and East Asia in particular dominate the fertilizer trade in the developing countries. Asia accounted for 77 percent of net fertilizer imports in 1994/95, and within Asia, East Asia accounted for 92 percent. Although there are more than 40 countries in Sub-Saharan Africa, this region accounts for less than 6 percent of the fertilizer trade in the developing countries. Because fertilizer trade plays an important role in meeting fertilizer requirements in many developing countries, macroeconomic policy becomes critical in developing a fertilizer supply strategy for promoting growth in fertilizer use.

Future Outlook

Fertilizer Demand

Fertilizer demand in 2020 is estimated using three different approaches. The first two approaches estimate fertilizer demand based on food production requirements and agronomic (nutrient removal) needs. The third method estimates effective demand based on a behavioral model by taking into account the effect of economic and noneconomic variables, such as foreign exchange availability, exchange rate, crop and fertilizer prices, and the development of irrigation and other infrastructure; it also considers the impact of policy reforms on fertilizer demand. The estimates derived from econometric methods under this approach are modified on the basis of qualitative information and informed judgments. Thus, these estimates indicate "positive" effective demand, whereas the estimates prepared under the first two methods suggest "normative" requirements.

The agronomic needs are estimated by using nutrient removal coefficients for various cereals and nutrient uptake efficiency rates. These estimates indicate how much fertilizer will be required if the nutrient reserves in the soils are maintained at their initial level. Likewise, fertilizer requirements based on food production needs indicate the amount of fertilizer nutrients needed to meet the food production requirements in 2020.

Effective Fertilizer Demand

Because fertilizer use decreased substantially during 1989/90–1994/95 and is expected to recover in the late 1990s, using 1994/95 as a base year could have generated unrealistically high growth rates. Hence, 1989/90 (hereafter referred to as 1990) is used as a base year to calculate long-term growth rates. During the 1990–2020 period, global fertilizer demand is projected to increase 1.2 percent per year. In absolute amounts, it is projected to increase from about 144 million tons in 1990 to 208 million tons in 2020 (Table 11). Global use of N, P_2O_5, and K_2O is projected to increase from 79, 38, and 27 million tons, respectively, in 1990 to 115, 56, and 37 million tons in 2020 (Table 12).

Most of the projected increase in global fertilizer use is expected to occur after 2000. Little growth is projected during the 1990–2000 period for several reasons. First, policy reforms and environmental regulations are expected to have a negative impact on fertilizer use in Western Europe. Second, economic and political reforms in Eastern Europe and Eurasia reduced fertilizer use drastically in the early to mid-1990s, and these regions are expected to have slow to moderate recovery in the late 1990s. The expected decline in fertilizer use in these regions will barely be compensated by the growth in fertilizer use in other regions including

Table 11—Fertilizer demand projections by region for total NPK, 2020

Region	1990[a]	2000	2010	2020
	(million metric tons)			
North America	20.9	22.1	24.0	26.0
Western Europe	22.1	15.7	16.7	18.5
Eastern Europe	9.3	6.5	8.2	10.1
Eurasia	24.5	16.3	19.4	24.0
Oceania	1.9	2.2	2.7	3.2
Africa	3.5	5.1	6.6	9.3
North	1.5	2.1	2.7	3.4
Sub-Saharan	1.2	1.9	3.0	4.2
South	0.8	1.1	1.4	1.7
Latin America	8.2	10.4	13.2	16.2
Central	2.9	3.2	4.0	4.8
South	5.3	7.2	9.2	11.4
Asia	53.2	69.7	85.3	100.7
East	34.2	43.5	51.6	58.6
South	14.8	20.6	26.8	33.8
West	4.2	5.6	6.9	8.3
World	143.6	148.0	176.6	208.0
Developed countries	81.3	65.7	74.7	86.4
Developing countries	62.3	82.3	101.9	121.6

Source: FAO 1994 for actual figures and IFDC 1994 for projections.
Notes: NPK = N + P_2O_5 + K_2O.
[a]The 1990 data are for actual consumption.

Asia and Latin America. Third, North America and Oceania may experience modest growth due to improved prospects for crop exports in the late 1990s. Fourth, structural adjustment programs and policy reforms are expected to reduce growth in fertilizer use in many developing countries. Thus, global fertilizer use may have a roller-coaster ride in the 1990s (Bumb 1995).

Better recovery in the reforming economies of Eastern Europe and Eurasia is expected to have a positive influence on growth in fertilizer use in the early twenty-first century. Fertilizer use is projected to increase at 1.9 to 2.2 percent per year in these regions during the 2000–2020 period. By 2020, however, fertilizer use in these regions will still only approximate the 1990 levels. Fertilizer use is projected to grow in North America, Western Europe, and Oceania at 1 to 2 percent per year. It is assumed that, by the year 2000, fertilizer use in Western Europe will have decreased to the minimum levels needed for crop production and environmental protection; hence, continued increase in demand for crop production for domestic use and exports may promote growth in fertilizer use at modest rates. Nevertheless, fertilizer use in 2020 is

Table 12—Fertilizer demand projections by region and nutrient, 1990–2020

Region	Nitrogen			Phosphate			Potash		
	1990[a]	2000	2020	1990[a]	2000	2020	1990[a]	2000	2020
	(million metric tons)			(million metric tons)			(million metric tons)		
North America	11.2	12.0	14.0	4.6	4.9	6.0	5.1	5.2	6.0
Western Europe	11.2	8.5	10.0	5.1	3.3	4.0	5.8	3.9	4.5
Eastern Europe	4.6	3.5	5.0	2.3	1.6	2.5	2.4	1.4	2.6
Eurasia	9.9	7.0	10.5	8.2	5.3	7.0	6.4	4.0	6.5
Oceania	0.5	0.8	1.2	1.1	1.1	1.5	0.3	0.3	0.5
Africa	2.0	2.8	5.4	1.1	1.6	2.6	0.4	0.7	1.3
North	1.0	1.3	2.0	0.4	0.6	1.0	0.1	0.2	0.4
Sub-Saharan	0.6	1.0	2.7	0.4	0.6	1.0	0.2	0.3	0.5
South	0.4	0.5	0.7	0.3	0.4	0.6	0.1	0.2	0.4
Latin America	3.8	4.6	7.0	2.4	3.1	5.0	2.0	2.7	4.2
Central	2.0	2.1	3.0	0.5	0.6	1.0	0.4	0.5	0.8
South	1.8	2.5	4.0	1.9	2.5	4.0	1.6	2.2	3.4
Asia	36.0	44.2	62.2	12.7	18.2	27.4	4.5	7.3	11.1
East	23.7	27.4	35.5	7.5	10.9	15.6	3.0	5.2	7.5
South	9.8	13.6	22.2	3.7	5.2	8.5	1.3	1.8	3.1
West	2.5	3.2	4.5	1.5	2.1	3.3	0.2	0.3	0.5
World	79.2	83.4	115.3	37.5	39.1	56.0	26.9	25.5	36.7
Developed countries	38.5	32.9	43.1	22.2	17.3	22.3	20.6	15.5	21.1
Developing countries	40.7	50.5	72.2	15.3	21.8	33.7	6.3	10.0	15.6

Source: FAO 1994 for actual figures and IFDC 1994 for projections.
[a]The 1990 data are for actual consumption.

projected to be 16 percent lower than it was in 1990 in Western Europe.

In Asia, Africa, and Latin America, fertilizer use is projected to grow by 1.8 to 2.4 percent per year. In absolute amounts, Asia is expected to increase its fertilizer use by 31 million tons and therefore would account for more than 50 percent of the growth in global fertilizer use between 2000 and 2020. During the same period, Latin America is expected to increase its fertilizer use by 5.8 million tons and Sub-Saharan Africa by 2.3 million tons. In contrast to the nutrient requirements for food production and resource conservation in Sub-Saharan Africa, the projected growth in fertilizer use is inadequate. About 8 to 10 percent annual growth in fertilizer use is needed in Sub-Saharan Africa. A high degree of political commitment to ensure a conducive policy environment, consisting of macroeconomic stability, price incentives, credit support, efficient organizations, and an adequate supply of physical and institutional infrastructure is required to promote fertilizer use. Because many countries depend on fertilizer imports, ensuring an adequate and timely supply of foreign exchange is also important. However, such growth must initially be concentrated in high-potential areas that are well served by markets and infrastructure and where agroecological conditions are favorable. Complementary measures must also be introduced to conserve the soils and protect the environment.

Table 13—Annual growth in fertilizer use by region, 1960–90 and 1990–2020

Region	1960–90	1990–2000	2000–2020	1990–2020
	(percent)			
North America	3.4	0.6	1.0	0.9
Western Europe	2.4	–3.4	0.8	–0.6
Eastern Europe	5.5	–3.6	2.2	0.3
Eurasia	7.9	–4.1	1.9	–0.1
Oceania	2.9	1.5	1.9	1.7
Africa	6.5	3.8	2.4	2.9
North	6.7	3.4	2.4	2.7
Sub-Saharan	8.3	4.6	2.6	3.3
South	4.6	3.2	2.2	2.5
Latin America	8.2	2.4	2.2	2.3
Central	7.6	0.9	2.5	1.7
South	8.6	3.0	2.3	2.6
Asia	9.3	2.7	1.8	2.1
East	8.3	2.4	1.5	1.8
South	12.0	3.3	2.4	2.8
West	12.5	2.9	2.0	2.3
World	5.5	0.3	1.7	1.2
Developed countries	4.0	–2.1	1.4	0.2
Developing countries	10.5	2.8	2.0	2.2

Source: Calculated from data in FAO 1994 and Table 12.

In contrast to the high annual growth in fertilizer use during the 1960–90 period, the projected growth rates during the 1990–2020 period are considerably lower at both global and regional levels for several reasons (Table 13). First, in 1960, fertilizer use levels were extremely low in many regions, especially in the developing countries; hence, growth in fertilizer use accelerated from a low base. But in 1990 fertilizer use in many regions was high; therefore, future growth rates are starting from a much higher base. For example, in contrast to 3.3 million tons in 1960, Asia used 53.3 million tons of fertilizer nutrients in 1990. Further, per hectare fertilizer use in many regions, including Western Europe and East Asia, is already at or above the agroeconomic optimum, limiting further growth. Second, economic and policy reforms, leading to devaluation of domestic currency, removal of fertilizer subsidies, and disruption of supply systems, are constraining growth in fertilizer use in many regions. Third, environmental regulations associated with fertilizer use are expected to limit growth in per hectare fertilizer use. Fourth, economic and environmental considerations are inducing farmers to improve fertilizer use efficiency by managing it properly; this may result in higher crop production with lower fertilizer use, especially in the developed countries.

Fertilizer Requirements

Fertilizer requirements estimated by the nutrient removal and cereal production approaches are presented in Table 14. Under the first approach, nutrients removed by rice (paddy), wheat, maize, and other cereals are estimated by using nutrient removal coefficients (FAO 1984; IFA 1992) and ce-

Table 14—Global fertilizer requirements, 2020

Economic Region	Nutrient Removal Approach	Cereal Production Approach
	(million nutrient tons)	
Developed countries	115.1	77.6
Developing countries	251.1	185.3
World	366.2	262.9

Source: Authors' calculations.

real production projections (Rosegrant, Agcaoili, and Perez 1995). Because crops remove only a fraction of applied fertilizer nutrients, an assumption about the nutrient uptake efficiency is essential. Several field studies indicate that nutrient uptake efficiency can vary between 11 percent and 82 percent, with a global average of 40 to 50 percent (Mosier 1995; Tandon 1993; Strong 1995; Smil 1994). It is therefore assumed that average nutrient uptake efficiency is 50 percent in the developed countries and 40 percent in the developing countries. It is further assumed that various technology- and policy-related measures will improve these rates by 30 percent in the developed countries and 20 percent in the developing countries by 2020. In the developed countries, crop residues are generally returned to the soils, whereas in the developing countries, they are used for fuel, fodder, and construction materials; hence it is assumed that only 50 percent of the crop residue will be returned to the soil in the developing countries.

Under the second approach, it is assumed that currently 1 ton of fertilizer nutrients yields 10 tons of cereal in the developing countries (FAO 1987) and 15 tons in the developed countries. It is expected that by 2020 technological and policy-related changes will improve these rates by 20 percent in the developing countries and 30 percent in the developed countries.

The fertilizer requirements for cereals estimated under both approaches are converted into total fertilizer requirements by assuming that cereals will account for 50 percent of the total fertilizer use in the developed countries and 55 percent in the developing countries. Agricultural diversification in the developing countries is expected to reduce the share of cereals in total fertilizer use from the current 66 percent to 55 percent in 2020. In the developed countries, where agriculture is already diversified, reduction of grain surpluses through the General Agreement on Tariffs and Trade (GATT) reforms may reduce this share by a small percentage—from 53 percent in 1988–91 to 50 percent in 2020.

On the basis of the nutrient removal approach, the world will need to use about 366 million tons of nutrients to replenish the nutrients removed from the soils. Even if the projected effective demand of 208 million tons is realized, there will be a gap of 158 million tons of nutrients that will affect the soils adversely. Of this gap, more than 80 percent (129 million tons) will occur in the developing countries. Under the cereal production approach, the world will need to use about 263 million tons, leaving a shortfall of 55 million tons. Under this approach, the developed countries will have a surplus of 8 million tons, whereas the developing countries will have a shortfall of 63 million tons. The shortfalls in the developing countries under these approaches will range between 45 and 105 percent of the projected effective demand. Although application of animal manure and atmospheric deposits would reduce a part of these shortfalls, the deficits will have an adverse effect on food security and resource conservation in the developing countries unless additional efforts are made to promote higher levels of fertilizer use in an environmentally sound manner.

Fertilizer Supply

The projections of supply potential developed by the World Bank/FAO/UNIDO Industry Fertilizer Working Group[11] (1994) and IFDC (Bumb 1995) suggest that the world will have the capacity to produce between 147 and 163 million tons of fertilizer nutrients in the year 2000. Thus, the world will need to plan to manufacture an additional 54 to 70 million tons of nutrients to meet the projected effective fertilizer demand in 2020.[12]

Estimates of supply potential in the year 2000 in Table 15 (Bumb 1995), prepared by using existing and planned capacity, operating rates, and conversion and distribution losses, indicate the maximum technical potential for supplying fertilizers on the basis of existing and planned capacities. The implicit assumption here is that, if the prices are right, then the industry will be able to supply about 87 million tons of N, 42 million tons of P_2O_5, and 29 million tons of K_2O in the year 2000. If prices remain depressed, actual supply may be lower than what is estimated here.

In the year 2000, Asia will account for 40 million tons, or 46 percent, of the global N supply potential.

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[11] UNIDO is the United Nations Industrial Development Organization. "Industry" refers to the fertilizer industry.

[12] Because marketing and distribution losses, in-transit shipments, and statistical errors account for about 4 percent of fertilizer production, only 96 percent is assumed to be available at the farm level; hence, to meet the projected demand of 208 million tons, the world must produce about 217 million tons of fertilizer nutrients.

Table 15—Fertilizer supply potential by region, 2000

Region	Nitrogen	Phosphate	Potash	Total
	(million metric tons)			
North America	10.8	10.8	11.4	33.0
Western Europe	9.0	2.7	5.7	17.4
Oceania	0.4	0.9	0	1.3
Eastern Europe	5.4	1.6	0	7.0
Eurasia	12.8	6.7	8.0	27.5
Africa	2.8	5.6	0	8.4
North	1.8	4.4	0	6.2
Sub-Saharan	0.5	0.4	0	0.9
South	0.4	0.8	0	1.2
Latin America	5.6	1.8	0.5	7.9
Central	3.7	0.6	0	4.3
South	2.0	1.2	0.5	3.7
Asia	39.9	11.4	3.2	54.5
East	22.3	7.3	0.6	30.2
South	11.9	1.4	0	13.3
West	5.7	2.7	2.6	11.0
World	86.7	41.5	28.8	157.0

Source: Bumb 1995.
Note: Totals may not add up due to rounding.

Eurasia, North America, and Western Europe will also be major producers of N. Asia, Eurasia, North America, and North Africa will be major P_2O_5 producers and North America and Eurasia will be major K_2O producers. Canada, Russia, and Belarus account for more than 75 percent of the current K_2O production capacity because most of the world's potash resources are concentrated in these countries.

Fertilizer Supply–Demand Balances

The fertilizer supply–demand balances based on the projected demand and estimated supply potential are presented in Table 16. For all three nutrients, supply potential will exceed the projected demand by 2–3 million tons at the global level in the year 2000. At the regional level, the situation differs considerably. In spite of Asia's dominant position in fertilizer production, East Asia and South Asia will experience deficits in all three nutrients. South America and Sub-Saharan Africa will also be deficit in all three nutrients. Central America will be surplus in N, North Africa in P_2O_5, and West Asia in N and K_2O.

Among the developed regions, Eurasia and Eastern Europe are expected to have surpluses in N, North America and Eurasia in P_2O_5, and North America, Western Europe, and Eurasia in K_2O. Overall, most of the surpluses will be concentrated in the developed countries and most of the deficits in the developing countries.

Table 16—Fertilizer supply–demand balances by region, 2000 and 2020

Region	2000 N	2000 P_2O_5	2000 K_2O	2000 Total	2020[a] N	2020[a] P_2O_5	2020[a] K_2O	2020[a] Total
	(million metric tons)				(million metric tons)			
North America	−1.2	5.9	6.2	10.9	−3.2	4.8	5.4	7.0
Western Europe	−0.5	−0.6	1.8	0.7	−1.0	−1.3	1.2	−1.1
Eastern Europe	1.9	0	−1.4	0.5	0.4	−0.9	−2.6	−3.1
Eurasia	5.8	1.4	4.0	11.2	2.3	−0.3	1.5	3.5
Oceania	0.4	−0.2	−0.3	−0.1	−0.8	−0.6	−0.5	−1.9
Africa	−0.1	4.0	−0.7	3.2	−2.6	3.0	−1.3	−0.9
North	0.5	3.8	−0.2	4.1	−0.2	3.4	−0.4	2.8
Sub-Saharan	−0.5	−0.2	−0.3	−1.0	−2.2	−0.6	−0.5	−3.3
South	−0.1	0.4	−0.2	−0.1	−0.3	0.2	−0.4	−0.5
Latin America	1.0	−1.3	−2.2	−2.5	−1.4	−3.2	−3.7	−8.3
Central	1.6	0	−0.5	1.1	0.7	−0.4	−0.8	−0.5
South	−0.5	−1.3	−1.7	−3.5	−2.0	−2.8	−2.9	−7.7
Asia	−4.3	−6.8	−4.1	−15.2	−22.3	−16.0	−7.9	−46.2
East	−5.1	−3.6	−4.6	−13.3	−13.2	−8.3	−6.9	−28.4
South	−1.7	−3.8	−1.8	−7.3	−10.3	−7.1	−3.1	−20.5
West	2.5	0.6	2.3	5.4	1.2	−0.6	2.1	2.7
World	3.3	2.3	3.3	8.9	−28.6	−14.5	−7.9	−51.1

Source: Derived from data in Tables 10 and 13.
Notes: Totals may not add up due to rounding. Balance is supply potential minus demand; minus signs indicate a deficit.
[a]Based on projected demand in 2020 and estimated supply potential in 2000.

The supply–demand balances for 2020 are estimated by assuming that fertilizer capacity will remain fixed at the 2000 level. This is done for two reasons. First, no estimates of planned capacity in 2020 are available. Second, this approach provides an estimate of the additional capacity needed to meet the fertilizer requirements in 2020, so that future investments can be planned.

The estimates in Table 16 indicate that the world will need additional fertilizer capacity to supply a total of 51 million tons of nutrients—about 29 million tons of N, 15 million tons of P_2O_5, and 8 million tons of K_2O. Asia will continue to have the largest deficits, accounting for more than 90 percent of the global deficits. Asia must continue to invest in fertilizer capacity while maximizing benefits from fertilizer trade. Overall, North America and Eurasia will maintain surplus positions in total fertilizer supply, although North America will be deficit in N fertilizers and Eurasia in P_2O_5 fertilizers. Most other regions will be deficit in two or more nutrients. Even without additional investment, however, North Africa will be able to export about 3 million tons of P_2O_5 in 2020.

Although natural gas is available in several other regions, Eurasia, West Asia, and Central America will remain the major surplus-producing regions for N. North America and North Africa will continue to be the major producers of P_2O_5 and North America and Eurasia of K_2O. Sub-Saharan Africa has plenty of phosphate rock reserves, as stated earlier, but high investment costs, low phosphate prices, foreign exchange shortages, and limited skilled manpower have prevented the development of these reserves either for domestic use or exports in the past. Besides direct application of phosphate rock as a soil amendment, Africa could produce partially acidulated phosphate rock (PAPR) or develop compacted materials, such as phosphate rock with triple superphosphate or other products for fertilizer applications (Chien and Hammond 1988).

It is obvious from these supply–demand balances that many developing regions will have to depend on trade to meet their fertilizer requirements during the 2000–2020 period. Given the high resource endowments and investment costs required, it would be undesirable to pursue a policy of fertilizer self-sufficiency in every region or country. Even some of the large countries such as Brazil, China, India, and Mexico should rely on trade and joint ventures to meet their future fertilizer requirements.

Will the world be able to produce enough fertilizer in 2020? To satisfy the projected effective fertilizer demand, fertilizer production should be increased by 51 million tons—at 1.4 percent per year during the 2000–2020 period.[13] Given the 5.7 percent annual growth of the 1960–90 period, reaching the required growth of 1.4 percent should not be difficult. What are the likely constraints?

Raw materials, capital investment, technology, and prices are four possible major constraints to fertilizer production. The first three are unlikely to be critical constraints. Natural gas, a prime hydrocarbon for producing N fertilizers, is available in large quantities (Table 17). Although natural gas has competing demands from other sectors, especially in South Asia, South America, Western Europe, and Eastern Europe, there is enough natural gas in other regions to produce N fertilizers for several decades. West Asia alone can produce enough N fertilizer to satisfy the world demand by converting the natural gas it flares into ammonia. Phosphate rock, the major feedstock for P2O5 fertilizers, is also readily available (Table 18).

Table 17—Natural gas reserves by region, estimated on January 1, 1992

Region	Reserves
	(trillion cubic feet)
North America,	266.1
Western Europe	178.5
Eastern Europe	16.4
Eurasia	1,750.0
Oceania	26.5
Africa	310.2
Latin America	238.5
West Asia[a]	1,319.1
East and South Asia	272.8
World	4,378.1

Source: Oil and Gas Journal Energy Database 1994.
[a]Includes the Middle East.

[13] To meet the projected fertilizer requirements under alternative approaches, fertilizer production should be increasing at an annual rate of 2.6–4.2 percent.

Table 18—Phosphate rock reserves in selected countries, 1990

Country	Reserves	Resources
	(million metric tons)	
China	210	210
Former Soviet Union	1,300	1,300
Israel	n.a.	190
Jordan	600	700
Morocco and Western Sahara	7,000	2,200
Senegal	160	160
South Africa	2,500	2,500
Togo	40	70
Tunisia	267	533
United States	1,300	5,200
Others	725	3,725
Total	14,102	36,588

Source: Van Kauwenbergh 1994.
Notes: Reserves are proven deposits and resources are potential reserves. n.a. is not available.

Only a fraction of the proven reserves is currently used to meet the global demand for P_2O_5.[14] Potash reserves will also not be a limiting factor in production of K_2O.

Many of the fertilizer-producing companies in the developed and the developing countries have funds available for capital investment. The low fertilizer prices and surpluses of the last few years have deterred investment. Even companies from developing countries such as China, India, and Pakistan are investing in joint ventures to ensure adequate supplies for domestic markets (Narayan and Bumb 1995). The only region that may not attract enough capital because of poor institutional and physical infrastructure, political instability, or an unstable policy environment is Sub-Saharan Africa. However, this region could import the required fertilizer from the global market, if foreign exchange were not a constraint.

Technologies for fertilizer production have improved considerably and are easily available in the global market. Most energy-efficient technologies for ammonia production were available for large plants (those with a daily capacity of at least 600 tons) in the 1970s, but now such technologies are also available for small plants.[15] The adoption of these technologies should reduce energy use considerably in the future. Energy use in modern N-producing plants decreased by about 35 percent during the 1970–90 period (Constant and Sheldrick 1992).

The last constraint is pricing. Global fertilizer prices have been low in the late 1980s and the early 1990s (Figure 9), which has induced closure of capacity in North America, Western Europe, and Oceania and reduced additional investments in the developing regions because investment in fertilizer production capacity has not been profitable. For example, investment in a new ammonia-urea complex at an existing site requires a minimum price of about $150 per ton as against the prevailing average price of $95 per ton in 1993. Similarly, investment in a diammonium phosphate plant requires a minimum price of about $250 per ton in contrast to the 1993 average price of $129 per ton.[16] Most of the capacity expansion occurred in the developing countries, where it was mostly need-based and partly subsidized.

There are two possibilities for the future. First, because most of the growth in demand is expected to occur in the developing countries, countries such as India and China may continue to make investments to meet the domestic demand for food security reasons, as they have done in the past, or they may develop joint ventures with resource-rich countries in West Asia and North Africa (Narayan and Bumb 1995). Second, the fertilizer industry is a demand-led industry: as demand catches up with the existing supply, especially after fertilizer use in the reforming economies recovers, fertilizer prices may increase to justify new investments.

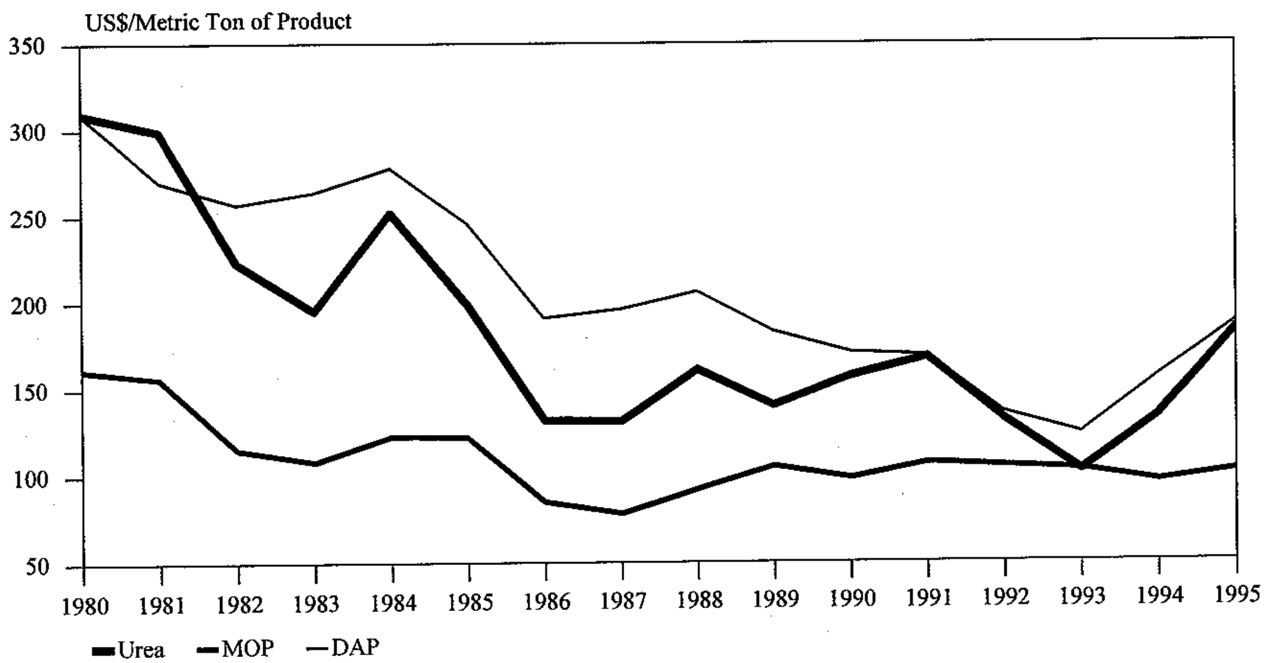
But increased prices may have two opposite effects. To reduce the gap between demand and supply and restore equilibrium, they may increase capacity and production and decrease fertilizer use. Unless the increased fertilizer use efficiency and improvements in nonprice factors counterbalance the negative price effect, food production may be adversely affected. On the other hand, increased

[14] In 1990, the world used about 7.3 trillion cubic feet equivalent of natural gas—about one-sixth of 1 percent of the total reserves—in producing N fertilizers. Likewise, less than one-tenth of 1 percent of phosphate rock reserves was used in producing phosphate fertilizers.

[15] One such technology is Imperial Chemicals leading concept ammonia process.

[16] Although fertilizer prices increased significantly in 1994 and 1995 due to a sudden increase in demand for fertilizer in North America (because of crop losses in the 1993 floods) and production shortages due to interruptions in the natural gas supply in Belarus and Ukraine, it is unlikely that prices will remain that high in the medium and long terms.

Figure 9—World fertilizer prices, 1980–95



Source: World Bank 1996.
Notes: Urea prices are f.o.b. bagged Western Europe, and diammonium phosphate (DAP) and muriate of potash (MOP) prices are f.o.b. bulk U.S. Gulf and Vancouver (Canada) respectively. All prices are in 1990 US$.

prices may also induce improvements in nutrient use efficiency, which is currently very low,[17] and thereby minimize the adverse effect on food production. More attention should be paid to improving nutrient use efficiency in the future because this improvement would not only compensate for the negative price effect but also create positive environmental benefits by reducing the amount of nutrients lost to the atmosphere. In any case, fertilizer shortages are unlikely to affect fertilizer use in the early twenty-first century.

Although creating an adequate fertilizer supply at the global level may not be a problem, many developing regions, especially Sub-Saharan Africa, South Asia, South America, and East Asia, will not be able to attain an adequate supply of fertilizer nutrients through domestic sources. The situation in Sub-Saharan Africa will remain precarious because of the region's limited production base and shortage of foreign exchange for imports. Because many developing countries will continue to depend on fertilizer imports to meet their fertilizer requirements, foreign exchange availability, exchange rate stability, and related policies will be critical to supply of fertilizer at the farm level.

[17] Currently, nutrient use efficiency averages between 40 and 50 percent. That is, 50 to 60 percent of the applied fertilizer nutrients are lost to the atmosphere.

4. *Policies to Sustain Growth in Fertilizer Use and Supply*

Several policies affect operations in the fertilizer sector, but the policies outlined below have a major impact and hence are elaborated in detail.[18]

Macroeconomic Policy

Growth in both fertilizer use and supply depends not only on microeconomic factors such as pricing, marketing, and credit availability, but also on the stability of macroeconomic factors such as the exchange rate, foreign exchange availability, inflationary pressures, and capital markets. Of these, foreign exchange rate stability probably has the most critical influence. The experiences of many developing and reforming countries such as Brazil, Mexico, Poland, Russia, Turkey, and Zambia suggest that rapid devaluation of the domestic currency leads to a sharp contraction of fertilizer use and production.[19] Although devaluation of domestic currency increases incentives for fertilizer exports, it also decreases domestic use by increasing price of both domestically produced and imported fertilizers (Table 19). Consequently, domestic production also falls. Furthermore, increased costs of imported raw materials and equipment also affect fertilizer production adversely. During such macroeconomic shocks, some safeguards or "safety nets" may be necessary to prevent the collapse of the fertilizer markets.

Inadequate availability of foreign exchange has affected the performance of the fertilizer sector in many developing countries. First, delays in getting adequate foreign exchange affect the construction cycle. In the developed countries, a fertilizer plant, say an ammonia-urea complex, can be completed in 18 to 30 months; in the developing countries, it could easily take 30 to 60 months. For example, the delay in obtaining adequate foreign exchange has delayed the

Table 19—Exchange rate and nitrogen prices in selected countries, 1985–90

Country	Local Currency	Exchange Rate 1985	Exchange Rate 1989	Exchange Rate Percent of Change	Nitrogen Price 1985	Nitrogen Price 1990	Nitrogen Price Percent of Change
		(local currency/US $)			(local currency/metric ton N)		
Asia							
Bangladesh	Taka	26.3	32.3	22.8	10,141	10,826	6.7
Turkey	Lira	522.0	2,121.7	306.5	112,970	552,174	388.8
Africa							
Ghana	Cedi	55.6	250.0	349.6	28,095	223,819	696.7
Zambia	Kwacha	0.9	12.9	1,333.3	1,125	16,696	1,384.1
Latin America							
Mexico	Peso	246.0	2,457.0	898.8	40,435	434,783	975.3
Venezuela	Bolivar	7.5	34.7	362.7	1,411	3,333	818.9
Eastern Europe							
Poland	Zloty	147.2	1,439.0	877.6	26,304	985,739	3,647.5

Source: IMF 1990 for exchange rate data and FAO various years a for nitrogen prices.

[18]This section draws heavily on Narayan and Bumb 1995. Also see Bumb et al. 1994.

[19]In countries where fertilizer use is excessive, a modest devaluation can help improve the efficiency of fertilizer use through price effects.

construction of Nigeria's NAFCON II plant by several months. Second, foreign exchange shortages have forced many developing countries to approach several different donors for financing of a plant. Because many donors provide "tied" aid, requiring use of their own equipment and parts, such arrangements lead to incompatible and inefficient fertilizer plants.[20] Third, inadequate supply of foreign exchange generally results in shortages of spare parts and raw materials, which lead to low capacity utilization. A 1990 World Bank study found that fertilizer plants in Zimbabwe operated at, near, or higher than design capacity, whereas in Zambia the operating rates never exceeded 50 percent. The major difference was that the government of Zimbabwe assigned top priority to allocating foreign exchange to the fertilizer industry, whereas operation and maintenance were poor in the Zambian fertilizer industry due to lack of spare parts, equipment, and raw materials—a result of foreign exchange shortages. Fourth, foreign exchange shortages generally affect the quantity and quality of fertilizer imports, thus restricting fertilizer use in many developing countries, particularly in Sub-Saharan Africa. Adequate and timely availability of foreign exchange is essential for promoting growth in both fertilizer use and supply.

Pricing Policy

After macroeconomic factors, pricing policy plays the most crucial role in the growth and performance of the fertilizer sector. First, fertilizer prices affect the incentive to use and produce fertilizers. Higher prices can discourage farmers from using fertilizers, whereas lower prices can promote excessive fertilizer use leading to environmental contamination.[21] On the other hand, higher prices can stimulate production and help introduce environmental protection measures, whereas lower prices can reduce the incentive to produce and ultimately lead to the closure of capacity, as happened in North America and Western Europe in the mid and late 1980s. Thus, the pricing of fertilizer poses the greatest challenge because it affects the interests of both producers and users (farmers) and ultimately of society through its impact on fertilizer use and food production. Second, fertilizer prices signal opportunities for new investment. Again, low prices can discourage investment in capacity building, whereas high prices can lead to excessive investment, as happened in the late 1970s and early 1980s. Third, pricing policy has a major effect on development of competitive marketing systems and marketing and distribution infrastructure. Highly regulated and unremunerative prices have discouraged their development. Finally, the pricing policy also affects the development of external trade in fertilizers.

It is clear from this impact analysis that the fertilizer pricing policy affects various segments of the industry and the society differently. Gains for fertilizer producers become losses for farmers and consumers and vice versa. Hence, the pricing policy should be designed to optimize the interests of everyone in the society—the producer, the trader, the farmer, and ultimately the consumer.

The multifaceted nature of the pricing policy has produced various price regimes in different developing countries (Segura, Shelty, and Nishimizu 1986). Broadly, these price regimes vary from free market pricing in Thailand to fully controlled pricing in Nigeria. In some developing countries, fertilizer prices are controlled at all levels; in others they are controlled only at the factory gate or the port level. In those countries where fertilizer prices are regulated, fertilizer subsidies have not been uncommon. China, India, Indonesia, and Saudi Arabia still subsidize fertilizers, whereas Ghana, the Philippines, Thailand, and Venezuela do not. With the implementation of structural adjustment programs and market reforms, the number of countries subsidizing fertilizer decreased significantly between the early 1980s and the early 1990s.

In many countries, especially those where fertilizer supplies were not constrained, fertilizer subsidies have promoted rapid growth in fertilizer use and food production (Couston and Narayan 1987). The most successful examples are China, India, Indonesia, Mexico, Nigeria, Saudi Arabia, Turkey, and Venezuela. Although fertilizer subsidies have played an important role in promoting food security through increased fertilizer use, they have become their own enemies because they have created unsustainable fiscal burdens. For example, in India, fertilizer subsidies amounted to US$1.4 billion (Rs 44 billion) or 3 percent of the national budget in 1993/94. Like fertilizer subsidies, crop price support pro-

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[20] India's Haldia fertilizer plant is a classic example. See Narayan and Bumb (1995) for details.

[21] High crop prices, by reducing the real price of fertilizer, can have similar effects.

grams and other producer support measures have also promoted high levels of fertilizer use in the developed countries (Table 20).

In those countries where fertilizer subsidies or crop price support programs or both have promoted excessive fertilizer use, the removal of subsidies and support measures will lead to the convergence of economic and environmental goals by promoting resource use efficiency, reducing fiscal deficits, and minimizing environmental damage. However, in those countries, especially in Sub-Saharan Africa, where fertilizer use levels are low and nutrient mining is contributing to environmental damage through soil degradation and deforestation, a strong case can be made for fertilizer subsidies, especially on P_2O_5 fertilizer, to restore and sustain soil fertility. Further, in landlocked countries where infrastructure is poorly developed and transportation costs are high, a subsidy on transportation costs may be desirable, so that farmers in such areas are not unnecessarily penalized. Because of poor infrastructure development and the small size of fertilizer markets, prices paid by African farmers are generally much higher than those paid by their Asian counterparts (Table 21). Before fertilizer subsidies are introduced, however, distortions in crop prices should be removed to improve incentives for fertilizer use. Even with subsidies, farmers in some remote locations may not find fertilizer use profitable. In such cases, alternative crop technologies should be promoted to increase food production and to protect the environment. In any case, fertilizer subsidies should be undertaken as a temporary measure to encourage fertilizer use where it is low, and subsidies should be withdrawn when fertilizer use is close to the economic and environmental optima.

In those countries where fertilizer subsidies have been in existence for a long time and their removal is desirable, a caution is warranted. The experience of several countries suggests that sudden, ad hoc removal of subsidies is not desirable because it may lead to a substantial decline in fertilizer use, as happened in Venezuela (Bumb 1989; Martinez 1989). A proper sequencing and phasing scheme should be developed, and compensating measures should be taken to prevent an adverse impact on fertilizer use and supply. Great caution should be used in phasing out subsidies during a period of macroeconomic instability. It may be advisable not to remove fertilizer subsidies especially during rapid devaluations, because this may lead to drastic reductions in fertilizer use, as happened in Ghana (Figure 10). Further analysis and research for developing feasible and socially desirable schemes for policy reforms are required.

Many developing countries have followed a policy of panterritorial pricing to promote equity in

Table 20—Producer supports in agriculture and fertilizer use

Country	Average Producer Subsidy Equivalent, 1979–89	Fertilizer Use, 1985[a]
	(percent)	(kilograms/hectare)
Argentina	–38[b]	4
Australia	11	24
Austria	36	255
Brazil	22[b]	42
Canada	35	50
European Community 10	39	303
Finland	62	210
India	–2[b]	50
Indonesia	11[b]	94[c]
Japan	68	427
Korea, Republic of	61[b]	376
New Zealand	20	30
Norway	73	277
Sweden	46	141
Switzerland	71	437
Thailand	–4[b]	21
United States	30	94

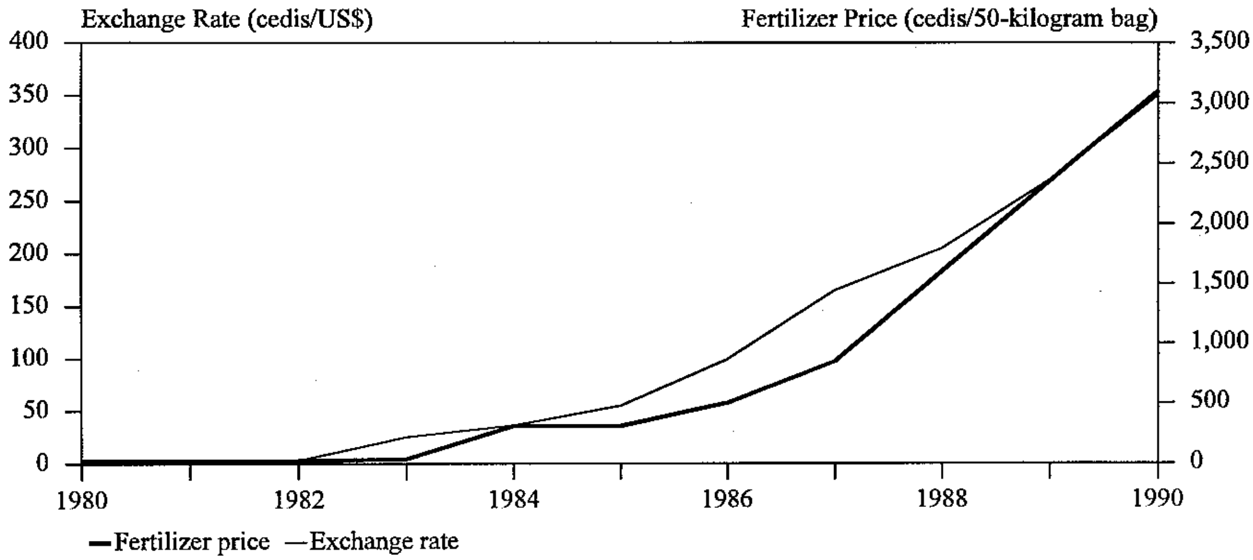
Source: Anderson 1991.
[a]Total consumption of N, P_2O_5, and K_2O fertilizers on arable land.
[b]Average producer subsidy equivalent for 1982–87 only.
[c]Fertilizers were highly subsidized.

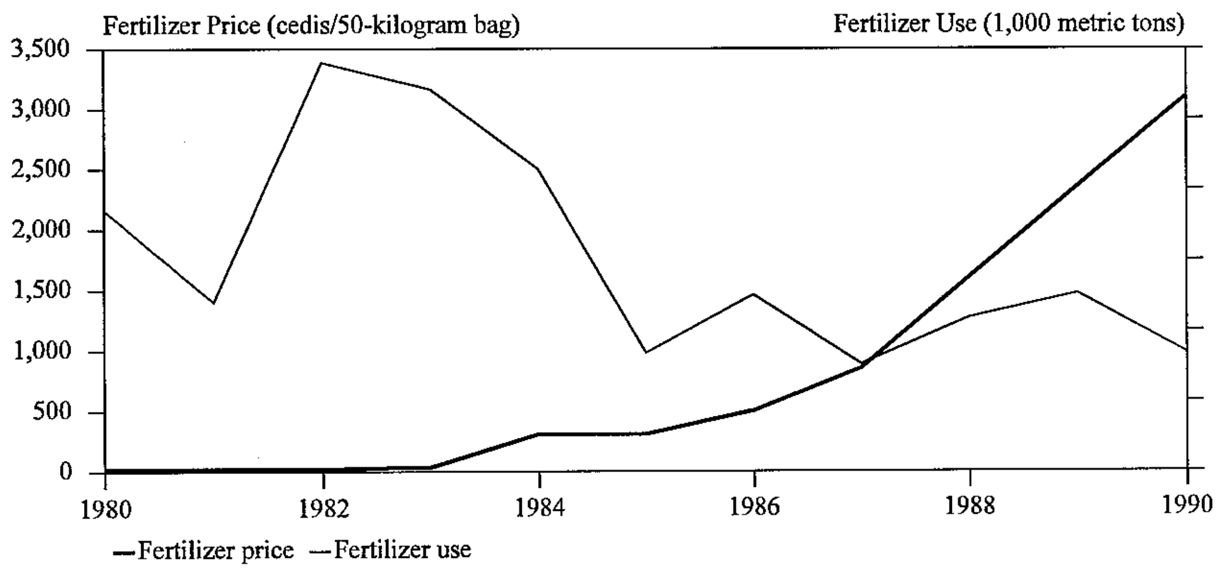
Table 21—Fertilizer prices paid by farmers, 1991/92

Country	Prices: Urea	DAP	MOP
	(US $/metric ton of product)		
Africa			
Morocco	249	257	188
Senegal	n.a.	365	n.a.
Zambia	256	n.a.	487
Zimbabwe	359	n.a.	232
Asia			
Bangladesh	126	140	136
India	118	181	66
Indonesia	110	n.a.	141
Nepal	120	176	68
Pakistan	162	201	n.a.

Source: Derived from data in FAO 1992 and FADINAP 1992.
Note: DAP is diammonium phosphate and MOP is muriate of potash. n.a. is not available.

Figure 10—Exchange rate, fertilizer price, and fertilizer use in Ghana, 1980–90





Source: Bumb et al. 1994.
Notes: Fertilizer quantities are in nutrient tons. Fertilizer price is for ammonium sulphate. During 1980–83, exchange rate and fertilizer price varied between 2.8 and 3.5 cedis per U.S. dollar and 12 to 25 cedis per 50-kilogram bag.

fertilizer use and food production, especially among small farmers. In the initial stages, such a policy may be desirable, but when the market is large, it acts as a constraint to improved marketing efficiency because it restricts freedom of pricing, which promotes competition and efficiency. Improving the supply situation and infrastructure facilities should receive higher priority than panterritorial pricing for promoting equitable use of fertilizers.

Credit Policy

In most developing countries, fertilizer accounts for a large proportion of cash expenditures incurred by small and medium farmers. Because such farmers are resource poor, they have to depend on borrowed funds to purchase fertilizer and other agricultural inputs. During the economic reform process, the need for funds further increases because devaluation and subsidy removal generally lead to increased prices for the purchased inputs. Consequently, many farmers have frequently identified the nonavailability of funds as a major constraint to agricultural production in general and fertilizer use in particular. In a survey of 700 farmers in Ghana, almost 93 percent identified credit as a major constraint to expanding agricultural production. The removal of fertilizer subsidies without a corresponding increase in the availability of credit funds may have contributed to a significant decline in fertilizer use in Venezuela during the early 1980s (Martinez 1989). Nonavailability of funds also contributed to the collapse of the fertilizer markets in the former centrally planned economies (Bumb 1995). Thus, the availability of adequate funds at reasonable interest rates continues to be critical in promoting fertilizer use in the developing and reforming countries.

In the past, many developing countries relied on subsidized interest rates and lending quotas to promote investment in the agriculture sector. Interest rates charged on agricultural loans were generally lower than those on commercial and industrial loans. For example, in Ghana, the interest rate on agricultural loans was 14.5 percent in contrast to 21.0 percent for other loans in 1985; by 1988, this differential was reduced to zero. In Nigeria, the interest rate for agricultural loans is still subsidized (IFDC–Africa 1994). These programs had mixed success, and their politicization led to overdue loans, poor loan recoveries, misuse of funds, and nonviable financial institutions. These trends led to the removal of subsidies and lending quotas for agriculture and resulted in an emphasis on the development of rural financial markets in the agricultural credit projects financed by donors, especially the World Bank. The development of financial networks and infrastructure in rural areas is important for mobilizing savings, for integrating rural markets into national financial networks, and for investing in agriculture and related activities. But their development alone is unlikely to promote the level of investment needed because agriculture is an inherently risky and uncertain business, and most small farmers are risk-averse and have poor collateral. After the removal of preferred interest rates in Ghana in 1988, the share of institutional lending to agriculture dropped from 32 percent in 1984 to 17 percent in 1988 and 8 percent in 1995. Hence a small differential in the interest rate should be maintained for agricultural loans; loan recoveries should be improved through better management of financial institutions, reduction of political interference, and integration of input and output markets.

In addition to providing credit to farmers for the purchase of fertilizers and other inputs, proper arrangements should be made to ensure adequate funds to fertilizer dealers, who will play an increasingly important role as fertilizer marketing and distribution are privatized in the developing and reforming countries. In the past, there was little need for this support because the parastatal agencies had a monopoly on fertilizer marketing and distribution, and their financial needs were met through allocations in the national budget. The private dealers do not have recourse to such support. Moreover, many dealers in rural areas, especially women traders in Africa, have limited resources to purchase fertilizer and other agricultural inputs from wholesalers and manufacturers and to maintain adequate stocks. Because fertilizer was not traded freely in the past, the banking institutions hesitated to advance loans to fertilizer dealers in those countries where the fertilizer market has recently been privatized, such as Albania and Bangladesh. A program to train dealers and bankers to participate in fertilizer trade will be needed. In order to ease the financial burdens on dealers, a program of warehouse collateral could be developed and fertilizer and grain trades could be integrated. Needless to say, success in this area is important not only for promoting fertilizer use at the farm level but also for making privatization a success story in many developing countries.

Marketing Policy

Efficient marketing and distribution arrangements are essential for improving the efficiency of both fertilizer use and supply. It is through marketing channels that fertilizer reaches the farmer on time, in the right quantity and quality, and at the right price. Untimely and inadequate supplies have hampered fertilizer use in many countries. Because fertilizer has to be applied on time for maximum crop benefit, fertilizer delayed is basically fertilizer denied. This creates a disincentive for farmers to use fertilizer and reduces demand, which in turn reduces growth in food production.

Foreign exchange shortages leading to restricted fertilizer supplies, price regulation, and subsidy administration have generally resulted in controlled fertilizer distribution systems in many developing countries. Parastatals and public sector agencies were created to distribute and import fertilizer. For example, P.T. Pupuk Sriwidjaja (PUSRI) in Indonesia and the Fertilizer Procurement and Distribution Division in Nigeria fully monopolize the distribution of fertilizer. The performance of public sector agencies has varied widely. In some countries, they were successful; in others, they became "rent-seeking" groups. In Nigeria, for example, a significant proportion of fertilizer dispatched from factories and ports is never delivered to farmers (Ogunfowora 1993). Moreover, such organizations become a burden on scarce fiscal resources because their operations are generally subsidized. Before the fertilizer marketing system was reformed and privatized in Bangladesh, administrative expenses of the Bangladesh Agricultural Development Corporation accounted for a major share of fertilizer subsidies (Ahmed 1993). After the reforms, fertilizer subsidies were eliminated, and improvements in marketing efficiency reduced the cost of fertilizer at the farm level.

Empirical evidence suggests that the public sector agencies or state-owned enterprises are less suited to efficient marketing than are private sector enterprises because they operate under soft budget constraints, enjoy less autonomy and authority, and are subject to political interference (Nellis 1991). They are guided relatively more by the bureaucratic process (rules and regulations) and less by the demands of business activities. Depending on the situation, the manager at the retail depot should have the authority to make decisions about prices and quantities. However, the nature of the bureaucratic process does not allow decisions to be made at that level because the decisionmaking process is generally from the top down. Hence, public sector organizations end up performing a distributive function. On the other hand, marketing organizations in a competitive market system have the authority to make decisions concerning the four Ps—product, price, promotion, and place. Through improvements in these areas, private sector organizations try to improve efficiency and reduce the cost of distribution. In addition, the freedom to enter or leave the fertilizer business ensures that most efficient marketers will stay in business because their operations are not subsidized. Thus, public sector agencies are less suited to the business of marketing fertilizers. That is why, in India in the mid-1960s, the Sivaraman Committee, appointed by the government to assess fertilizer marketing options, recommended freedom of marketing and abolished the monopoly of cooperatives in fertilizer distribution. In sum, the private sector should play a dominant role in fertilizer marketing and distribution.[22]

Nevertheless, the public sector has an important role in ensuring efficient functioning of the fertilizer market by performing regulatory functions. It should enact and implement legislation to ensure the quality of products and to protect the environment. It should safeguard against collusion among sellers resulting in a monopoly and should develop monitoring mechanisms (information management systems) to prevent unwarranted increases in prices. The government should also develop financial, physical, and institutional infrastructure to promote smooth functioning and integration of the fertilizer markets.

Having identified the appropriate roles of the public and private sectors in promoting efficient marketing of fertilizers, the next issue is how to move from a fully state-regulated, public monopoly system to a private competitive market system, or how to privatize the state-owned and -managed marketing and distribution systems. There are several possibilities, but two of them merit special discussion because they deal with the speed with which the public sector agencies should withdraw from marketing and distribution to make room for the private sector dealers. The proponents of the first approach, generally known as the "big bang" approach, advocate that the state agencies should withdraw *rapidly* from marketing and production activities, so that the private sector can take over and develop free market systems. The proponents of the second approach—the gradualist approach—however, suggest that the government should withdraw *gradually* because the development of management skills and institutional infrastructure is a slow, time-consuming process. If the government withdraws without developing the requisite skills and infrastructure, the fertilizer market may collapse, and fertilizer use and production may decrease so drastically that it could take many years to recover.

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[22]The private sector is used here in a generic sense. All organizations including cooperatives and parastatals following the rules of the competitive market system are assumed to be private sector enterprises.

Many countries in Eastern Europe, Eurasia, and Africa have followed the big-bang approach without much success. Within a short span of three to four years, fertilizer use has decreased perhaps as much as two-thirds because the private sector did not have the necessary capacity and skills to replace the countrywide networks of marketing channels. As a result, farmers do not have easy access to fertilizer. Of course, rapid devaluation and subsidy removal have also contributed to the collapse of fertilizer markets. The learning period needed to acquire new skills and develop capacity is not long enough when the change is so rapid.

A few countries such as Bangladesh and China have followed the gradualist approach to market reforms. In Bangladesh, privatization of fertilizer marketing and distribution was introduced step by step: first, retail marketing was privatized; then wholesale marketing, followed by fertilizer imports. At each step, the necessary management skills and institutional infrastructure were developed (Ahmed 1993). Although this sequence created bottom-up pressures for reforms, it took nearly 13 years before imports could be privatized. Whereas in other countries, such as Ghana, Poland, Russia, and Zambia, fertilizer use decreased during the reform process, in Bangladesh, fertilizer use increased at an annual rate of 8 percent during the 1980–93 period, even after subsidies were removed and fertilizer marketing and imports were fully privatized. This limited evidence suggests that a gradualist approach to marketing reforms is preferable to the big-bang approach. Additional work is needed to understand the dynamics of organizational reforms in this and other areas.

Trade Policy and Regulation

Although the developing countries as a group are not self-sufficient in fertilizer production, the degree of self-sufficiency varies among countries and regions. For example, Central America and West Asia are major exporters of N fertilizer, and North Africa is a major exporter of P_2O_5 fertilizer. East Asia, South America, South Asia, and Sub-Saharan Africa are major importers of all three nutrients. At the country level, Indonesia, Iraq, Kuwait, Mexico, Saudi Arabia, and Trinidad and Tobago are major N exporters, and Jordan, Morocco, Senegal, and Tunisia are major P_2O_5 exporters. Few developing countries, except Jordan, have enough capacity to export K_2O fertilizer. On the import side, Brazil, China, India, Malaysia, and Turkey are major importers.

In spite of heavy dependence on imports, most developing countries have pursued a regulatory trade policy and allowed little freedom of trade in fertilizer in the past. Recently, some countries, including Brazil, Kenya, Mexico, Turkey, and Venezuela, have deregulated trade in all fertilizer products, and India has demonopolized and deregulated imports of P_2O_5 and K_2O fertilizer.

The regulatory trade policy of the past was tied to two main factors: (1) fixed exchange rate regimes and foreign exchange shortages, and (2) protection of both domestic fertilizer producers and farmers from the volatility of international fertilizer prices. To implement this policy, most developing-country governments created parastatals such as the Minerals and Metals Trading Corporation (MMTC) in India, Sinochem in China, and NAMBOARD in Zambia. In other countries, such as Ghana and Nigeria, the responsibility for fertilizer imports remained with the Ministry of Agriculture.

In either mode, the responsible agency had full monopoly over imports of fertilizer. Such arrangements had advantages and disadvantages. On the positive side, countries could benefit from economies of scale in bulk imports and lower prices and could regulate supplies to achieve a balance between domestic production and imports. Under such conditions, the policymakers had more leverage in promoting growth of the domestic fertilizer industry and in economizing on foreign exchange through better price deals. The most successful country in this area is China whose Sinochem imported fertilizer at highly cost-effective prices. India's MMTC was also effective in getting good price deals.

On the negative side, such arrangements have resulted in rent-seeking and corrupt practices, leading to an untimely, inadequate, and unsuitable supply of fertilizer in many countries. In such cases, fertilizer has become a political commodity. Being in a monopolistic position, the agency has less incentive to improve its performance. And the cost of its inefficiency is borne by all the users—whether farmers, traders, or producers—waiting for raw materials. This is perhaps the biggest disadvantage.

In addition to the disadvantages associated with monopolistic import arrangements, the regulatory trade policies also affect the performance of the domestic industry. Because domestic producers are protected from foreign competition, they have little incentive to improve their efficiency. As a result, farmers pay higher prices in a protected sellers market, as happened in the Philippines in the early to mid 1980s.

Although many countries have controlled the import and export of fertilizer through quotas, few countries except Thailand and Argentina have imposed tariffs on fertilizer imports because most countries have wanted to promote growth in fertilizer use through subsidies and other measures. Because fertilizer will remain a critical component of the food security strategy in many developing countries, a no-tariff policy should continue into the future as well.

Future performance and growth of the fertilizer industry at the national level will depend on a conducive trade policy, designed to protect the interests of both fertilizer producers and farmers. From this point of view, there are two issues that require detailed discussion: free trade in fertilizer and phasing and sequencing of trade policy reforms.

Should the developing countries embrace a policy of free trade in fertilizer? In general, a move toward free trade would be desirable in the long run because it would help improve production efficiency and widen choices about products and technologies. The major advantage of such a policy would be a reduction in the subsidies that have protected inefficient factories. However, given the uncertainties of international markets and the long gestation period needed for investing and building capacities, a completely free trade would transmit the shocks and volatility of international markets to domestic fertilizer markets and thereby introduce uncertainties in food production that may endanger food security. Yet a complete regulation of trade and monopolistic arrangements would also be undesirable because these would perpetuate inefficiencies, fiscal burdens, and rent-seeking behavior. Therefore, the developing countries should follow a middle path, a path of "managed" markets in which, through proper monitoring and evaluation of trade policy, gentle pressures—with breathing spaces—are exerted on domestic producers to improve their efficiency. Under such a scheme, they would be given access to foreign exchange and foreign technology, including raw materials and improved maintenance and operating procedures, to enhance their performance. If some companies, even with such incentives, are not able to improve their performance in a period of three to five years, they should be liquidated.

The second issue deals with the phasing of trade policy reforms. Just like the marketing policy reforms, the trade policy reforms can also be introduced rapidly or gradually. For the reasons mentioned earlier, a gradual approach to policy reforms is preferable because the big-bang approach, in the short run, could destroy the industry through the influx of unrealistically cheap fertilizer from abroad. In the long run, it could force the country to pay higher prices. The sudden deregulation of P_2O_5 fertilizer in India in 1993 vividly illustrates the drawbacks of a sudden liberalization (Narayan and Bumb 1995).

Investment Atmosphere and Government Incentives

The fertilizer industry is both capital-intensive and foreign-exchange intensive. For a large-scale ammonia-urea plant, capital investment requirements range from \$300 million to \$600 million, depending on the location of the plant. The lower amount is for an additional plant at an existing location, whereas the higher amount is for a "greenfield" project, a project in a remote location without any infrastructure in a developing country. In many countries in Africa, where infrastructure is underdeveloped, the required investment may be higher, although it is questionable that the entire cost of developing infrastructure should be charged to a single project. Ideally, infrastructure development should be treated as a social cost and charged to a social overhead development account in the national budget. Charging infrastructure costs to a single project puts the developing-country fertilizer industry at a great comparative disadvantage.

Due to the huge capital requirements, the economies of scale, and the risky nature of investment, few private companies were willing to invest in fertilizer production facilities in the 1960s and the early 1970s. Consequently, many developing-country governments created public sector organizations for investing in fertilizer production facilities. For example, until the late 1980s, most of the fertilizer production in Brazil, Mexico, Pakistan, Turkey, and Venezuela was controlled by state-owned enterprises. In Bangladesh, China, Egypt, Indonesia, Malaysia, Morocco, Nigeria, Saudi Arabia, Senegal, and Tunisia, fertilizer production is still under public sector control. In India, fertilizer production has been under all three sectors—public, private, and cooperative, including joint ventures. India has also taken the lead in developing joint ventures with other developing-country fertilizer enterprises.

In the past, several reasons were used to justify state-owned enterprises. First, there was a strong need to promote fertilizer use to ensure food security. One way to ensure a secure supply was to promote domestic fertilizer production. Second, given the capital intensity and foreign exchange requirements and the volatility of global fertilizer prices, the private sector was not keen to invest in fertilizer production; it also lacked the necessary financial and managerial capacity. The government was in a better position to take risks on investments. Third, the panterritorial pricing and subsidy policies pursued by many developing countries also favored state-owned enterprises because implementation was administratively easy; it required only the transfer of resources in the budget. Fourth, because the World Bank only lends funds to national governments, only state-owned enterprises could obtain World Bank financing for fertilizer production.

The government's involvement in the fertilizer sector was a mixed blessing. On the positive side, it provided the needed "big push" to increase fertilizer production to meet the growing fertilizer demand. As a result, fertilizer production increased more than eightfold—from about 6 million tons in 1969/70 to 52 million tons in 1992/93 in the developing countries. The increase in N production was even more spectacular: it increased more than ninefold—from less than 4 million tons to about 38 million tons. It is unlikely that exclusive reliance on the private sector could have generated this type of growth in the 1970s and the 1980s. This was a result of easy availability of natural gas in many developing countries, especially in Asia. For the reasons explained earlier, however, Sub-Saharan Africa did not experience such spectacular growth.

On the negative side, the overall performance of many state-owned enterprises was less than satisfactory for several reasons, including political interference, inadequate allocation of foreign exchange for the import of equipment and raw materials, insufficient autonomy and authority for decisionmaking and implementation, and poor incentive structures and operation and management. Many of these plants, operating under weak financial discipline, became a financial burden on the national budget and sustained their operations through subsidies. Because management had little accountability and authority, it paid little attention to improving plant operations to reduce costs and save energy. As a result, these plants became heavy users of energy.

Nevertheless, many public sector plants in India, Indonesia, Mexico, Nigeria, and Saudi Arabia have been well operated because the management had the authority, autonomy, and incentive to operate the plant on sound management principles. In this respect, many World Bank-financed plants score high because conditions imposed by the Bank ensured competent management and adequate finances for the operation of the plant (World Bank 1989).

Although ownership is important because it makes the necessary investment, it is management that determines the performance of a plant. Hence, as long as state-owned enterprises are managed competently and the government gives management the autonomy and authority to operate the plant, makes it accountable with proper incentives, and refrains from political interference, there may be no problem with state ownership. Moreover, in the developed countries, ownership and management are separated by shareholders and management contracts. Thus, in those countries where the fertilizer sector is in its infancy and the private sector is not capable of raising funds or willing to take the risks—many African countries, for example—ownership of fertilizer production facilities may stay with the government, provided the government ensures that the plant is run by a competent management team. But in those countries where the fertilizer market is large, financial markets are well developed, and the private sector has the ability and willingness to invest, the government should gradually withdraw from the fertilizer sector.

This leads to the issue of privatization. Should all fertilizer plants be privatized? This issue has to be determined in the context of socioeconomic goals, the nature of food and fertilizer security, the level of development of the fertilizer sector, and the capacity of the private sector to take risks and make the investments required to meet the growing demand at reasonable prices. However, it remains the responsibility of the government to ensure that privatization does not result in a monopolistic market structure.

The private sector will play an increasingly important role in owning and managing fertilizer production facilities in the future. Hence, the developing-country governments should create an enabling policy environment for private sector involvement, which will require the following actions.

1. The government should provide adequate foreign exchange on a timely basis so that

the investor can have access to the best proven technology and equipment for fertilizer production.

2. If both public and private sector plants are involved in fertilizer production, then the government should treat both fairly and make the playing field level; that is, producers in both sectors should have access to the same facilities and privileges.

3. To encourage investment, the government should provide incentives through tax holidays, investment credits, and tax rebates.

4. The government should ensure adequate availability of feedstocks (natural gas and power) and other raw materials.

5. The government should manage its trade policy in such a way that it does not create unnecessary problems for the industry, as happened in India. A policy of gradual liberalization should be pursued so that the domestic industry can prepare itself to face the competition.

6. The government should promote fair competition among producers by preventing collusion among producers through antitrust and quality control laws.

7. The government should not impose tariffs and taxes on imported fertilizer raw material and parts.

8. The government should not control fertilizer prices and markets, because price and market controls hamper the efficiency of production.

9. The fertilizer industry is a capital-intensive industry; hence, making adequate funds available for investment and renovation is crucial. In those countries where capital markets are not fully developed and the government controls most of the financial institutions, every effort should be made to ensure adequate funds.

10. The government should provide support for research and development and technology transfer so that the industry can benefit from advanced technologies in production and environmental protection.

5. Energy Implications

The critics have argued that fertilizer use is not desirable, first, because it takes up considerable amounts of nonrenewable energy resources, especially hydrocarbons, and, second, because it harms the environment. The environmental concerns about fertilizer are discussed in the next chapter.

Of the three major nutrients, N production requires the maximum amount of energy both as a raw material (commonly referred to as a feedstock by industry sources) and as a fuel for processing. P and K are mostly derived from mined phosphate rock and potash ores,[23] respectively, and therefore require modest quantities of energy for processing (Mudahar and Hignett 1982).

Nearly all N fertilizer products—urea, ammonium nitrate, ammonium sulfate, and nitrogen solutions—are produced from ammonia (NH_3), which is derived by combining one unit of N and three units of hydrogen (H). N is readily available in the atmosphere, but most crops (legumes are the exception) cannot use it directly; it has to be converted into a usable form through a reaction with H derived from water and hydrocarbons. Natural gas, naphtha, fuel oil, and coal are the hydrocarbons most commonly used in the production of ammonia and N fertilizer. However, natural gas-based technology uses the least amount of energy in ammonia production (Table 22). It is not surprising that a large proportion of ammonia plants built in the late 1970s and the 1980s are natural gas-based plants or that many natural gas-rich regions and countries are major producers and exporters of N fertilizers. China is the only country that produces more than 50 percent of its N in small-scale, coal-based plants (Constant and Sheldrick 1992).

Energy efficiency in ammonia plants has improved considerably during the last 20 years, especially since the energy crises of the 1970s. Most plants built in the late 1980s use moderate-to-low amounts of energy. Because existing ammonia capacity consists of different feedstocks, vintages, and processes, however, energy consumption varies from one country to another (Table 23). Inadequate operation and maintenance, subsidized low natural gas prices, and inefficient organizational arrangements have also contributed to high energy consumption in fertilizer plants. Improvements in these areas offer a considerable scope for enhancing energy efficiency in the future.

Table 22—Energy requirements in ammonia production

Raw Material	Energy Requirements
	(million Btu/metric ton of ammonia)
Natural gas	27.8
Naphtha	30.2
Fuel oil	33.7
Coal	38.9

Source: UNIDO/IFDC n.d.
Note: 1 Btu (British thermal unit) is equal to the quantity of heat required to raise the temperature of 1 pound mass of water by 1 degree Fahrenheit at a specified temperature (such as 39°F).

To estimate the energy requirements of the fertilizer sector, a weighted average of the energy consumed in the production, distribution, and use of various fertilizer products in 1990 is used. In estimating the energy requirements in 2020, it is assumed that energy efficiency will improve by 20 to 30 percent in the developing countries and the former centrally planned economies of Eastern Europe and Eurasia and by 10 percent in the developed markets of North America, Western Europe, and Oceania. A smaller percentage is assumed for the latter because high energy costs of the 1970s and early 1980s and low fertilizer prices of the mid to late 1980s have forced considerable improvements in energy conservation through plant closures, re-

[23]A small proportion of the global K_2O capacity is based on sea brines.

Table 23—Energy consumed in ammonia production in selected countries

Country	Energy Consumption
	(million Btu/metric ton)
United States	39.4
India	37.2–56.2[a]
Indonesia	37.4[b]
China	
Small plants	61.1[c]
Medium plants	51.6
Large plants	35.7
Russia	50.6
United Kingdom	33.0
Best modern plant	26.0–28.0[d]

Sources: United States: TFI 1994; India: The Fertiliser Association of India unpublished data; Indonesia: Hidayat 1994; Russia: Aleinov 1993; China and United Kingdom: personal communication.

Note: Data in this table should be considered indicative because these are estimates compiled from various published and unpublished sources.

[a]The lower quantity is for natural gas-based plants and the higher quantity is for fuel oil-based plants.

[b]Based on energy use in PUSRI II, III, and IV Plants after revamping. Before revamping, it averaged 42.2 million Btu/ton.

[c]Small plants use coal and large plants use natural gas as feedstocks. Medium plants use various feedstocks.

[d]These are design norms. In practice, energy consumption may vary between 28 and 30 million Btu/ton.

vamping, and replacement of old capacity by new plants that employ the latest energy-efficient technologies. The globalization and privatization of fertilizer markets and removal of subsidies on feedstocks and fertilizer production are expected to generate similar pressures for energy use efficiency in the reforming and developing markets. For example, many enterprises in Eastern Europe and Eurasia are seeking joint ventures for investments to improve the energy efficiency of their fertilizer plants (Sharovatova 1993). Similarly, a reduction in a subsidy on natural gas in Indonesia has motivated its fertilizer industry to launch a program to revamp its ammonia and urea plants to reduce energy use by 10 to 20 percent (Hidayat 1994). China has also initiated a program to reduce the share of small coal-based plants in ammonia production so that overall energy efficiency can improve in the future. The gradual replacement of old plants will generally lower future energy consumption.

Table 24—Energy used in the fertilizer sector, 1990 and 2020

Year/Economic Region	N	P_2O_5	K_2O	Total
	(trillion Btu)			
1990				
Developed regions	3,113.92	388.18	324.93	3,827.03
Developing regions	3,177.44	232.24	30.86	3,440.54
World	6,291.36	620.42	355.79	7,267.57
Ratio[a] (percent)	1.79	0.18	0.10	2.07
2020				
Developed regions	2,175.42	283.45	224.66	2,683.53
Developing regions	5,069.70	528.56	212.45	5,810.71
World	7,245.12	812.01	437.11	8,494.24
Ratio[a] (percent)	1.36	0.15	0.08	1.59

Source: Authors calculations.

[a]This is the ratio of energy use in the fertilizer sector to global energy consumption (350,660 trillion Btu in 1990 and 531,902 trillion Btu in 2020 (moderate growth scenario). Data on global energy consumption are from World Energy Council Commission 1993.

In 1990, the world used about 7,268 trillion British thermal units (Btu) of primary energy in fertilizer production; distribution, including packaging and transportation; and use (Table 24). Of this, N fertilizer accounted for about 86.5 percent. P_2O_5 and K_2O fertilizers accounted for 8.5 percent and 5 percent, respectively. The shares of developed and developing countries in the global energy use for fertilizer were 53 percent and 47 percent, respectively.

Although the production of fertilizer is energy-intensive, only about 2 percent of global energy consumption and less than 10 percent of U.S. energy consumption went to the global fertilizer sector.[24] In light of the contribution made by fertilizer to sustaining the Green Revolution and thereby ensuring food security to millions of people in Asia and other parts of the world, the amount of energy used is hardly worth arguing about. From the benefit-cost point of view, for every 1 million Btu of energy use[25] in the fertilizer sector, the world was able to produce an additional 218 kilograms of grain—enough to provide the minimum calorie intake for one person per year. Knowing that in 1990 the energy (natural gas) price averaged about $1 to $2 per million Btu, converting energy into food security through fertilizer (and associated inputs) of-

[24]According to the Oil and Gas Journal Energy Database (1994), in 1990, the United States consumed 81,170 trillion Btu of primary energy.

[25]This is equivalent to the energy used in driving from Washington, D.C., to New York City in a family car yielding about 25 miles per gallon of gasoline.

fers the most cost-effective and humane alternative for use of energy resources in the world.

By 2020, energy use in the fertilizer sector is expected to increase to 8,494 trillion Btu—about 1.6 percent of global energy consumption. Because of expected improvements in energy efficiency in fertilizer production, energy consumption is projected to increase by 17 percent, a much smaller percentage than fertilizer demand (45 percent). Of course, if fertilizer production is increased to meet the normative fertilizer requirements in 2020, then energy requirements will be higher than what is stated here. Even then, energy consumed in the fertilizer sector will remain a small fraction of global energy consumption in 2020—much less than what people will use driving personal cars.

6. Environmental Concerns

Fertilizer in general and N fertilizer in particular are at the center of a controversy. The advocates of judicious fertilizer use argue that fertilizer is indispensable for promoting food production, and it is needed in large quantities in developing countries; their opponents argue that fertilizer pollutes the environment. There are merits to both arguments, and both groups tend to exaggerate their claims. Well-managed fertilizer use can contribute to increased food production and reduced degradation of natural resources. But excessive use of fertilizer can also contribute to nitrate leaching, eutrophication, cadmium uptake by plants, and greenhouse gas emissions. It must be stressed, however, that fertilizer is not alone in causing pollution. In many cases, especially in Western Europe, pollution has been caused by excess animal manure (Leuck et al. 1995). Thus, a balanced perspective on fertilizer is required so that food production is maximized, soils are maintained in a productive state, and environmental pollution is minimized. The beneficial effects of fertilizer on food production and the environment have already been discussed; hence, this chapter deals with the adverse effects on the environment associated with fertilizer use and production and the means of addressing them.

Environmental impacts associated with fertilizer can be divided into the effects associated with fertilizer use and those associated with fertilizer production. In each category, impacts can be further distinguished by the source of the pollution—where it occurs. Most of the pollution problems associated with fertilizer production occur at the point of production. They include disposal of phosphogypsum; emissions of fluorine, sulfur dioxide, and nitrous oxides; and waste water disposal from production facilities. Because these pollutants occur near the factory, they can easily be controlled. On the other hand, nitrate leaching and eutrophication are associated with fertilizer use; they fall in the category of nonpoint pollution. In these cases, the polluter is separated from the polluted objects, and therefore the pollution problems are difficult to control through punitive measures. For example, when fertilizer is carried away by water runoff or soil erosion, it may contaminate lakes or rivers and result in eutrophication, leading to algae growth. It is difficult to fix the responsibility for that pollution because the damage occurs far from the site of pollution: the "polluter pays" principle cannot be easily applied. Similarly, groundwater can be contaminated by excess N from organic matter such as legumes and animal manures, from inorganic fertilizer, or from natural sources such as mineralization of soil as well as from sewage sludge, septic tank drainage, or industrial waste. Hence, it is difficult to implicate a single source, say fertilizer, without adequate monitoring, measurement, and analysis.

Environmental Concerns Associated with Fertilizer Use

Of the three main fertilizer types, only K_2O fertilizer has no known adverse effects on the environment. N and P_2O_5 fertilizer, when not managed properly, can affect the environment adversely.

Nitrate Leaching

High levels of nitrates in drinking water are considered harmful to human health, especially to infants who receive water in juices and formula, because they can cause a rare condition called methemoglobemia, or what is known as blue-baby syndrome. The World Health Organization has recommended that nitrate levels in drinking water should not exceed 50 milligrams of nitrate per liter of water. Both the European Union (EU) and the Environmental Protection Agency of the United States have recommended monitoring nitrate levels in water and taking corrective measures in those areas where nitrate levels exceed the recommended limits (EPA 1990; Commission of the European Communities 1991).

When N supply exceeds N uptake by plants and sufficient rainfall or irrigation occurs to saturate the soil, nitrates can be leached regardless of the source of N—from soil organic matter, animal manure, fertilizer, or legumes. For example, in spite of low levels of fertilizer use in Runnels County, Texas, U.S.A., nitrates in groundwater averaged over 250 milligrams per liter with a maximum of 3,000 milligrams. These levels were due to mineralization of soil N resulting from the plowing of grasslands (Conway and Pretty 1991). When fertilizer is the major source of pollution, it is usually in areas of vegetable production or irrigated sandy soil. Fertilizer is usually not the sole source of nitrate pollution; Leuck et al. (1995) estimated that a 50 percent tax on nitrogen use in the European Union could reduce N use and grain production without having a significant impact on nitrate levels, especially in Belgium, Denmark, and the Netherlands where animal manure is a major source of nitrate. In these countries, the N supply from animal manure exceeds the N supply from fertilizers by 14 to 91 percent (Table 25). Consequently, soil is oversaturated with N, causing nitrate leaching and runoff. Unless there is a decrease in the livestock population, the nitrate problem cannot be resolved in these countries.

The Nitrate Directive of the European Union, which passed into legislation in 1991, aims to control the net supply of N (supply minus uptake) to the soil beginning in 1999 (Leuck et al. 1995). The N fertilizer management plan of the state of Minnesota in the United States also recommends that an N budget based on the residual N in the soil, crop uptake, and supply of N from all sources should be prepared to develop environmentally friendly N fertilizer recommendations. Special measures are recommended to reduce N supply in those areas where nitrate levels exceed the recommended safe levels (Nitrogen Fertilizer Task Force 1990). Nonagricultural sources can also contribute to nitrate contamination of ground and surface waters. In several developing countries, high nitrate levels in the water were associated with sewage disposal, septic tank drainage, and industrial wastes (Conway and Pretty 1991). It is obvious from these instances and measures that the regulation of fertilizer application rates alone may not help in reducing nitrate levels in the water, if other sources of nitrates exist in an area.

Experimental studies have shown that nitrate leaching is correlated with N applications higher than the agronomic maximum (Figure 11). Hence it is desirable to keep N application rates below it. If N supply is available only from fertilizer, an application rate slightly below the agronomic maximum can serve as an environmental optimum. If N is available from other sources such as animal manure or legumes, then the application rate should be adjusted, as is suggested in both the EU and Minnesota plans. What is an environmentally optimum N application rate? This question cannot be answered easily because the agronomic maximum rate depends on the type of crop grown, soil texture, climate, and the method and timing of fertilizer application. Nevertheless, experiments in the United States suggest that grain yields continue to increase up to fertilizer application rates of 180 kilograms of N per hectare; at that level, little N is left in the soil to be leached (Keeney 1982).

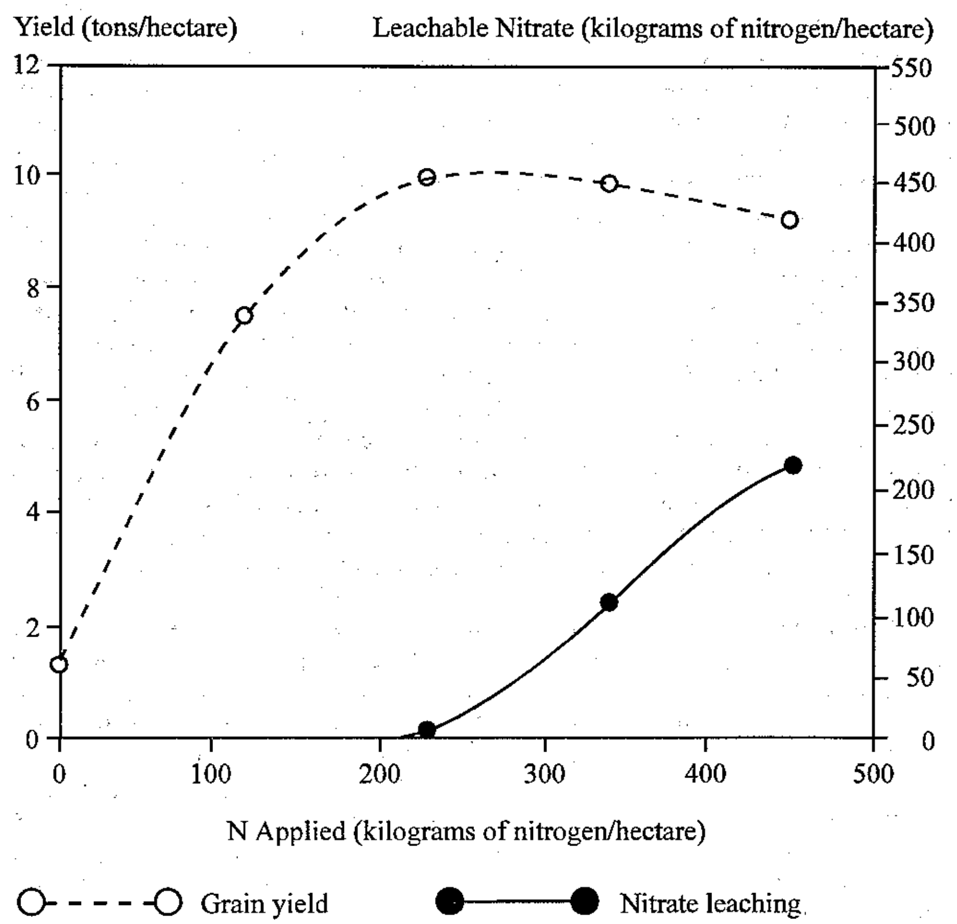
In general, N fertilizer does not pose a major nitrate contamination threat to the groundwater in developing countries because N application rates are low, ranging from 5 kilograms per hectare in Sub-Saharan Africa to 50 kilograms per hectare in South Asia. In East Asia, they average 149 kilograms per hectare, but mostly on flooded rice crops,

Table 25—Nitrogen (N) input from animal manure and fertilizer in selected countries in Western Europe

Country	N Supply: Manure	N Supply: Fertilizer	N Supply: Total	N Uptake by Crops	Residual N[a]: Total	Residual N[a]: Per Hectare
			(1,000 metric tons)			(kilograms)
Belgium[b]	380	199	580	211	369	240
Denmark	434	381	816	287	529	187
The Netherlands	752	504	1,255	285	970	480

Source: Leuck et al. 1995.
Note: Totals may not add up due to rounding.
[a]Because N is lost to the atmosphere, only a part of the residual N stays in the soil for possible nitrate leaching.
[b]Includes Luxembourg.

Figure 11—The effect of nitrogen application on nitrate leaching and yield



Source: Broadbent and Rauschkolb 1977.

from which little nitrate leaching occurs.[26] Further, the application of crop residue and animal manure is generally minimal (except in China) because these materials are used for fuel, fodder, and construction materials. Thus, inadequate application rather than overuse of N may be a major environmental problem in these countries. Nevertheless, in some areas where N application rates are high, soils are sandy, and rainfall is heavy, better fertilizer management practices and environmental monitoring should be introduced.

In developing policies and programs, it must be stressed that, in both developed and developing countries, nitrate leaching is generally a local problem; solutions should be targeted to correct these problems at the local level so that crop production in other areas is not unnecessarily penalized (Leuck et al. 1995; Kellogg, Maisel, and Goss 1994). In addition, efforts should be made to optimize the efficiency of N use through better control of the rate, timing, and method of application; modification of products; integration of farming and livestock activities; and improved cultural practices (Strong 1995).

Eutrophication

When P_2O_5 and N fertilizer is carried away by water runoff and soil erosion to lakes, ponds, rivers, and other water bodies, it contributes to excessive

[26]Nitrate runoff from paddy fields in East Asia may be a problem. However, little research and environmental monitoring has occurred in this area. Research on nitrate runoff should receive high priority in the future.

growth of algae, which can result in oxygen depletion and fish mortality. The aesthetic and recreational value of water bodies is also reduced. Eutrophication is basically a fertilizer management problem and can be prevented by reducing erosion and runoff.

Cadmium

When taken in large quantities, cadmium is hazardous to human health. The World Health Organization guidelines (WHO 1972) suggest that cadmium intake of up to 1 microgram per kilogram of body weight per day is not harmful to humans. Just as nitrate leaching can occur from several sources, cadmium levels in the soil can also increase from P_2O_5 fertilizer, animal waste, sewage sludge, and industrial and atmospheric deposits. In P_2O_5 fertilizer, cadmium comes from phosphate rock. Many sedimentary phosphate rocks found in Morocco, Togo, Tunisia, and the United States have high levels of cadmium, ranging between 35 and 55 milligrams per kilogram of rock (Böckman et al. 1990). However, the mechanisms by which cadmium is transferred from direct applications of phosphate rock or finished P_2O_5 fertilizer to soil, plants, and humans are complex and require further research. At the Rothamsted Station (in Hertfordshire, U.K.), even after 100 years of use of P_2O_5 fertilizer, an insignificant amount of cadmium was found in grains, whereas leafy crops, such as tobacco and spinach, had picked up a considerable amount of cadmium from the soil (Johnston and Jones 1992). A review of soil samples and plant tissues from some developing countries where phosphate rock had been used for a long time (at some sites over 40 years) also revealed low cadmium concentrations (IFDC 1993). Additional research is needed to develop proper regulatory measures. In any case, because P_2O_5 fertilizer use is still limited in the developing countries, it is unlikely to pose a major health risk in the near future. Even in Western Europe, where P_2O_5 fertilizer has been applied in higher rates over longer periods, cadmium intakes have, on average, been low (Isherwood 1992).

The Greenhouse Gases

Some scientists have predicted that increasing concentrations of gases such as carbon dioxide, nitrous oxide, and methane in the atmosphere will cause rising temperatures and global warming. The whole issue of global warming is controversial; nevertheless, fertilizer use and production have the potential to contribute to several of these gases. Oxides of N can emanate from N fertilizer use, especially in paddy fields, and CO_2 from fertilizer production facilities. However, the contribution made by fertilizer to greenhouse gases is likely to be negligible (Byrnes 1990; IFDC 1993). Better understanding through more research is needed rather than regulatory measures. As discussed earlier, well-managed fertilizer use can actually reduce global warming by sequestering carbon in the soil organic matter.

Environmental Concerns Associated with Fertilizer Production

The environmental concerns associated with fertilizer production are few and well understood; technologies to minimize their adverse effects in most cases are also well known. The major issue remaining pertains to the cost of installing technologies and who should pay those costs. That question will be discussed following a brief summary of the main pollutants associated with fertilizer production.

Pollutants Associated With Nitrogen Production

The pollutants associated with ammonia and urea production come in various forms—gases, liquids, and solids; discharge of these pollutants can adversely affect the community and the atmosphere. For example, the discharge of wastewater from ammonia plants can add to nitrate levels, and the emission of nitrous oxide, sulfur dioxide, and CO_2 can contribute to greenhouse gases and acid rain. With proper technologies and regulation, these emissions and pollutants can be minimized (Frederick and Lazo de la Vega 1992).

Pollutants Associated With Phosphate Production

Phosphogypsum is a by-product of production of phosphoric acid. For every ton of phosphoric acid produced, 4 to 5 tons of phosphogypsum are produced. Because phosphogypsum contains radium, it can emit radon, a radioactive gas, which is hazardous to both humans and animals. To safeguard against its harmful effects, phosphogypsum should be deposited in covered stacks or ponds. Although it can be used for agricultural, industrial, and road building purposes, economic considerations do not justify such uses on a large scale (Isherwood 1992; Schultz, Gregory, and Engelstad 1992). Disposing of phosphogypsum in an environmentally friendly way would have cost \$5 to \$80 per ton of P_2O_5 in the United States in 1988/89 (Schultz, Gregory, and Engelstad 1992). In addition, land reclamation would have added \$1 to \$5 per ton and process water treatment another \$20 to \$70 per ton. Treating these pollutants in the phosphate industry in 1988/89 would have increased the cost of production of DAP by \$34 to \$175 per ton of P_2O_5 in the United States alone (Table 26). Although these cost estimates pertain to the United States, they are indicative of the cost implications of environmental measures in other countries.

Policy Measures for Environmental Protection

Environmental problems in general and those related to the fertilizer industry in particular can be attributed to three factors: market failure, policy failure, and the knowledge gap (Bumb 1992). The market failure argument suggests that environmental problems are caused by the nonexistence of markets for environmental goods. For example, a

Table 26—Impact of environmental compliance on cost of fertilizer production, 1988/89

Product	US \$/Ton of Phosphate
Phosphate rock (PR)	4
Single superphosphate (SSP)	4
Partially acidulated phosphate rock—sulphuric acid based (PAPR-SA)	4
Nitrogen, phosphorus, and potassium (NPK) (Odda process)	4
Nitrogen, phosphorus, and potassium (NPK) (mixed acid process)	19–90
Partially acidulated phosphate rock—phosphoric acid based (PAPR-PA)	19–90
Triple superphosphate (TSP)	24–124
Monoammonium phosphate (MAP)	34–175
Diammonium phosphate (DAP)	34–175

Source: Schultz, Gregory, and Engelstad 1992.
Notes: The large variation in cost is a result of variations in environmental compliance or regulatory measures implemented by various states in the United States.

fertilizer factory dumps waste products—say, phosphogypsum—in the river because it is a free good and no one owns it. Subsequently, if the factory is required to pay the cost of treating the river, then it will find ways to prevent the damage caused by the pollutants. In economics, this is known as "internalizing the externality." The policy failure argument suggests that the pursuance of wrong policies can lead to environmental damage. For example, excessive crop price support programs and input subsidies contribute to excessive use of agrochemicals such as pesticides, causing harm to both humans and the environment. The knowledge gap argument implies that lack of proper knowledge about technologies, products, and practices leads to environmental damage. Eutrophication resulting from fertilizer runoff is an example of knowledge failure. Based on these and other factors, the following policy measures should be implemented.

- The "internalizing the externality" argument suggests that the cost of treating pollutants should be paid by fertilizer producers where pollution is related to production and by farmers where pollutants result from fertilizer use. This argument poses several problems because fertilizer use plays an important role in food production. Thus, the increased cost of environmental measures would lead to increased cost of fertilizer production, which in turn would lead to increased cost of food production and higher food prices paid by consumers. How much of the increased cost can be transmitted from producers to consumers depends on the price elasticity of demand and supply at each stage. Because, ultimately, consumers will bear the burden, a case can be made to provide some "social support" or cost-sharing arrangements for implementing environmental measures in the fertilizer industry.
- Unless the policy of internalizing the externality is implemented by all countries at about the same time, the early bird countries—those that first adopt the policy—will be losers. Hence, a global consensus should be developed for implementing environmental measures. Also, realistic guidelines about environmental regulation based on sound research should be developed.
- Crop price support programs and input subsidies that lead to excessive fertilizer use

should be reduced or removed. Such reforms will contribute to both economic and environmental goals.

- Technologies to deal with fertilizer pollutants are available in the developed countries. To transfer these technologies to the developing countries, foreign exchange and trained production staff are needed. Policymakers and donors should provide the necessary help in technology transfer.

- Policies for environmental monitoring should be introduced, especially in those developing areas where fertilizer use levels are excessive, and proper fertilizer management practices should be encouraged through research, extension, and education of farmers. Further research should be conducted to increase understanding of the environmental interactions of fertilizer production and use.

7. Future Challenges

Fertilizer use will remain an essential component of future strategies for ensuring food security and protecting the natural resource base. In fulfilling that role, however, fertilizer should be approached differently in the future. In the past, the main focus was on promoting growth in fertilizer use, and therefore all efforts—technical, organizational, institutional, infrastructural, and policy-related—were geared to that goal. And, in all fairness, it must be said that the developing countries (mostly Asian) that encouraged rapid growth in fertilizer use reaped rich dividends in increased food production and food security.[27] But in many countries, this growth was associated with increased fiscal burdens, high energy use, low fertilizer use efficiency, inefficient parastatals, and little environmental monitoring. All this will have to change because these costs are unsustainable. New strategies do a better job of promoting complementarities between economic and environmental goals and generating congruences among efficiency, equity, fiscal prudence, and environmental protection objectives.

In the future, the emphasis should be on "growth with management" rather than "growth" per se. This implies not only the management of fertilizer nutrients on the farm, but also the management of all resources—physical, human, financial, organizational, and policy—that go into the fertilizer sector. Although better management of all of these resources will promote efficiency, equity, fiscal prudence, and environmental protection under most circumstances, it will also create conflicts or trade-offs in some areas, which should be carefully managed without sacrificing the broader goals of food security, agricultural growth, and environmental protection. This new strategy of growth with management will involve challenges in several areas.

Resource Use Efficiency

In contrast to the developed countries, resource use efficiency in both the developing countries and the reforming economies is low in many areas. Inefficiencies in fertilizer use and energy consumption warrant special discussion.

Fertilizer Use Efficiency

Crop response to fertilizer use varies from one agroecological zone to another, and in the same agroecological zone, from one crop to another. On average, 1 ton of fertilizer nutrients yields about 10 tons of grain in the developing countries (FAO 1987). This is extremely low compared with the 15 to 20 tons of grain per ton of fertilizer nutrients achieved in North America and Western Europe. In rice production, N uptake by plants averages 30 to 35 percent in most Asian countries. Overall, fertilizer use efficiency (nutrient uptake by plants) in the developing countries may not exceed 40 percent. This indicates that considerable amounts of applied fertilizer nutrients are lost to the atmosphere and potentially damaging to the environment. Higher nutrient uptake by plants would limit nutrient losses to the atmosphere and reduce the need for fertilizer subsidies by improving the profitability of applied fertilizer nutrients. Thus, improving nutrient uptake efficiency or fertilizer use efficiency would promote both economic benefits and environmental protection.

Proper timing, application, and products can reduce nutrient losses. Soil analyses can also help in matching nutrient applications with plant requirements. In North America, many large farmers use computers to identify nutrient requirements in different parts of the field. In contrast to uniform

[27] Vaidyanathan (1993) estimated that about 60 percent of the increase in cereal production during the 1960–90 period in India was due to increased fertilizer use.

broadcasting, this practice, known as precision application, results in considerable savings in applied plant nutrients (Samson 1995; Dunn 1995). Although most small farmers in developing countries cannot afford this information technology, their governments can help them by providing better soil analyses and information on nutrient needs. Deep placement of fertilizer products, especially urea-diammonium phosphate (DAP) briquettes, in rice fields can also reduce fertilizer losses significantly (Savant and Stangel 1990).

Another means of improving nutrient use efficiency is to move from low- to high-analysis fertilizer products. Many farmers in the developing countries, especially in Sub-Saharan Africa, still depend on low-analysis fertilizer products such as ammonium sulfate (20.5 percent N) and single superphosphate (18 percent P_2O_5) rather than high-analysis fertilizer products such as urea (46 percent N), triple superphosphate (TSP) (46 percent P_2O_5), and DAP (18 percent N, 46 percent P_2O_5). In addition, over 8 million tons of N fertilizer used in China is ammonium bicarbonate (ABC)—a highly unstable and low-efficiency product. Under a program to convert its 1,000 or more small ABC plants into urea plants, China had converted about 75 such plants by 1992. This process will help to improve nitrogen use efficiency, if the pace of conversion can be accelerated.

Improving nutrient balances (the $N:P_2O_5:K_2O$ ratio) can enhance nutrient use efficiency. As indicated earlier, in many developing countries, N use, in relation to P_2O_5 and K_2O use, is excessive. This reduces the efficiency of N use. In some parts of China, K_2O and P_2O_5 deficiencies are so acute that farmers get little response from additional application of N (Zhu 1991). Although China has started programs to increase P_2O_5 and K_2O use, it has a long way to go. Many other developing countries should also pay greater attention to this area. Many developing countries have to depend on imported P_2O_5 and K_2O fertilizer; therefore, they have a tendency to save foreign exchange by minimizing imports. But such a policy does more social harm than good, because it reduces returns on investment in N fertilizer, causes harm to the environment, and leads to the degradation of soils in the long run.

In addition to these technology-related improvements, the developed and the developing countries can also improve fertilizer use efficiency by removing policy distortions. Reducing subsidies on fertilizer and crop production can motivate farmers to improve the efficiency of applied fertilizer. The experience of U.S. farmers in the 1980s is instructive. Low crop prices and financial hardships forced many farmers to improve nutrient use efficiency. Consequently, farmers managed to increase crop yields without increasing N fertilizer use (Table 27). Reduced fertilizer subsidies can motivate farmers to improve nutrient use efficiency, especially in those countries where fertilizer use is excessive. Another policy change that will help promote nutrient use efficiency is to allocate adequate foreign exchange on a priority basis for the import of P_2O_5 and K_2O fertilizers and to provide adequate credit and incentives to farmers to enhance their use.

Table 27—Maize production and N fertilizer use in the United States

Three-Year Average	Maize Production		N Fertilizer Used on Maize	
	Total	Yield	Total	Per Hectare
	(million metric tons)	(kilograms/ hectare)	(1,000 tons)	(kilograms/ hectare)
1980–82	208.5	7,022	4,897	150.2
1990–92	225.4	8,037	4,339	144.6

Sources: Derived from data in USDA 1992 and 1995 and Taylor 1994.

Energy Consumption Efficiency

Improving energy consumption efficiency in fertilizer production, especially N production, is a major challenge for many countries, especially China. High energy consumption is a result of several factors including outdated technologies, inadequate maintenance, inefficient organizational arrangements, and poor financial support. Subsidies on fertilizer production and raw materials have also contributed. Technologies for improving energy efficiency are available, but management commitment and financial resources, especially foreign exchange, are lacking. Multilateral institutions such as the World Bank and others can provide support for transferring these technologies.

- Old fertilizer plants should be replaced with plants that incorporate efficient, proven technologies.
- Revamping and rationalization operations should be used to reduce energy use.
- Adequate funds should be allocated for plant maintenance and repairs. Most plants in East-

ern Europe and Eurasia have received little maintenance in the past. Rehabilitating those plants would be costly now.

- Subsidies on raw materials and production should be reduced and production units should be exposed to competitive market pressures.
- Competent and autonomous management teams with authority and accountability should be installed.

Improving energy efficiency in China's small-scale ammonia plants is a major challenge. These plants use locally available coal (anthracite and semi-anthracite) and produce a low-quality product (ABC). Although these plants are often near the farm—an advantage—energy consumption is two to three times the energy use in modern, large-scale ammonia plants based on natural gas. China should develop a plan to gradually replace these plants with large-scale ammonia-urea plants, thus reducing CO_2 emissions to the atmosphere.

Policy and Organizational Reforms

Many developing and reforming countries are introducing policy reforms to restructure their economies in general and fertilizer sector operations in particular. Unless these policy changes are phased and sequenced properly, they may cause steep reductions in fertilizer use, as has happened in many countries including Ghana, Poland, Russia, Venezuela, and Zambia (Bumb 1989; 1995).

Although several policies affect fertilizer sector operations, policies dealing with devaluation, subsidy removal, and privatization seem to have a profound impact (Bumb 1995). The depreciation of domestic currency (devaluation) generally results in increased fertilizer prices for farmers and higher raw material and equipment prices for fertilizer producers. Consequently, fertilizer use decreases because crop prices generally do not keep up with the resulting inflation. Therefore, real fertilizer prices increase, as they did, for example, in Ghana, where they rose 12-fold during the 1980s when the value of currency changed from 3 cedi to the U.S. dollar in 1980 to 350 cedi to the dollar in 1990. The removal of fertilizer subsidies at the same time only adds to the declining trend. Thus, during rapid devaluation, some safety nets should be put in place to prevent too sharp a decrease in fertilizer use. Furthermore, when the fertilizer market is shrinking due to devaluation and subsidy removal, sudden withdrawal of the government from production, import, marketing, and distribution to promote privatization is not desirable. Successful privatization is a slow and time-consuming process, requiring investment in institutional and physical infrastructure and management skills.

On the other hand, when devaluation, subsidy removal, and privatization are introduced gradually and are supported by the development of adequate human and institutional infrastructure and regulatory mechanisms, they promote growth in fertilizer use, as happened in Bangladesh. Thus, policy reforms should be introduced in such a way that they promote growth in fertilizer use.

Environmental Protection

Because fertilizer use levels were low in many developing countries in the past, there was little need to be concerned about the environmental impacts associated with fertilizer use. In the future, however, environmental monitoring should receive higher priority because fertilizer use levels are climbing rapidly in some developing countries, especially in East Asia.

Promoting future growth in fertilizer use without causing harm to the environment will pose several challenges. First, to reduce the knowledge gap, farmers will have to learn how to apply fertilizer properly and efficiently. Because many developing-country farmers are illiterate, this will require a large effort. Second, additional research will be needed to understand the dynamic interaction of fertilizer use with the environment. Developing programs to reduce runoff losses, cadmium uptake by plants, and nitrate leaching from fertilizer and nonfertilizer sources will require further research and technology development work. New management practices will have to be developed. Third, policies will have to be redesigned: Although the removal of fertilizer and crop subsidies that lead to excessive fertilizer use is a high priority, new incentives to promote environmentally friendly agronomic practices, such as cereal-legume rotations, should also receive adequate attention. Generally, pricing policy is a better tool than regulatory policy (such as quantity restrictions on fertilizer use), although pricing policy alone (including taxes on fertilizer use) may not be sufficient to reduce or eliminate environmental damage; other policies and programs leading to better knowledge and practices should be encouraged.

Human and Institutional Capacity Building

In the past growth in fertilizer use and production in many developing and reforming countries was brought about through the all-pervasive involvement of the government or public sector agencies. Increasing fiscal burdens, lower efficiency, and the demise of communism have initiated a move toward competitive market systems in many countries. But a successful transition from a public sector monopoly or centrally planned economy to a competitive market system requires an adequate supply of human and institutional infrastructure. Management and marketing skills, regulatory mechanisms, financial institutions, and information networks are essential for efficient functioning of market-based food and fertilizer sectors. In many countries, such skills, institutions, and infrastructure are in short supply. Thus, there is an urgent need to provide training and technical assistance to develop these skills and institutions. Reforming countries have a dire need for them, but many developing countries, especially in Sub-Saharan Africa, also need support in developing infrastructure. Without an adequate supply of such skills and institutions, deregulated market systems could degenerate into inefficient private monopolies.

Although these challenges are daunting, their successful resolution will help reduce poverty, promote food security, and protect the environment. Because the nature and scope of these challenges and the mechanisms to deal with them will differ from country to country, no uniform recipe can be provided. However, it must be stressed that a successful resolution will require a high degree of political commitment and pragmatic solutions leading to conducive and stable policies, appropriate organizational arrangements, and adequate institutional and physical infrastructure.

Appendix: Regional Classification of Countries

Table 28—Regional classification of countries

North America	Western Europe	Eastern Europe	Eurasia[a]	Oceania	Africa	Latin America	Asia
Canada	Austria	Albania	Armenia	Australia	*Sub-Saharan Africa*	*Central America*	*West Asia*
United States[b]	Belgium-	Bosnia-	Azerbaijan	Christmas Island	Angola	Bahamas	Bahrain
	Luxembourg	Herzegovina[d]	Belarus	Fiji	Benin	Barbados	Cyprus
	Denmark	Bulgaria	Estonia	French Polynesia	Botswana	Belize	Iran
	Finland	Croatia[d]	Georgia	New Caledonia	Burkina Faso	Bermuda	Iraq
	France	Czech Republic[e]	Kazakhstan	New Zealand	Burundi	Costa Rica	Israel
	Germany[c]	Hungary	Kyrgyzstan	Papua New	Cameroon	Cuba	Jordan
	Greece	Macedonia[d]	Latvia	Guinea	Cape Verde	Dominica	Kuwait
	Iceland	Poland	Lithuania	Samoa	Central African	Dominican	Lebanon
	Ireland	Serbia and	Moldova		Republic	Republic	Oman
	Italy	Montenegro[d]	Russia		Chad	El Salvador	Qatar
	Malta	Slovakia[e]	Tajikistan		Comoros	Grenada	Saudi Arabia
	Netherlands	Slovenia[d]	Turkmenistan		Congo	Guadeloupe	Syria
	Norway	Romania	Ukraine		Cote d Ivoire	Guatemala	Turkey
	Portugal		Uzbekistan		Djibouti	Haiti	United Arab
	Spain				Equatorial Guinea	Honduras	Emirates
	Sweden				Eritrea	Jamaica	Yemen[f]
	Switzerland				Ethiopia	Martinique	
	United Kingdom				Gabon	Mexico	*South Asia*
					Gambia	Netherlands	Afghanistan
					Ghana	Antilles	Bangladesh
					Guinea	Nicaragua	Bhutan
					Guinea Bissau	Panama	India
					Kenya	Saint Kitts	Myanmar
					Lesotho	and Nevis	Nepal
					Liberia	Saint Lucia	Pakistan
					Madagascar	Saint Vincent	Sri Lanka
					Malawi	and the	
					Mali	Grenadines	*East Asia*
					Mauritania	Trinidad and	Brunei
					Mauritius	Tobago	Darussalam
					Mozambique	Virgin Islands	Cambodia
					Namibia		China
					Niger	*South America*	Indonesia
					Nigeria	Argentina	Japan
					Reunion	Bolivia	Korea, DPR
					Rwanda	Brazil	Korea,
					Senegal	Chile	Republic of
					Seychelles	Colombia	Laos
					Sierra Leone	Ecuador	Malaysia
					Somalia	French Guiana	Mongolia
					Sudan	Guyana	Nauru
					Swaziland	Paraguay	Philippines
					Tanzania	Peru	Singapore
					Togo	Suriname	Taiwan
					Uganda	Uruguay	Thailand
					Zaire	Venezuela	Viet Nam
					Zambia		
					Zimbabwe		

Regional classification of countries—continued

North America	Western Europe	Eastern Europe	Eurasia[a]	Oceania	Africa	Latin America	Asia
							(*Continued*)
					South Africa		
					Republic of South Africa		
					North Africa		
					Algeria		
					Egypt		
					Libya		
					Morocco		
					Tunisia		

Notes: This classification system is that used by the International Fertilizer Development Center. Developed countriy regions include North America, Western Europe, Eastern Europe, Eurasia, Japan, Israel, South Africa, Australia, and New Zealand. Developing country regions include Latin America, Asia (except Japan and Israel), Africa (except South Africa), and Oceania (except Australia and New Zealand).

[a]Consists of the newly independent states (NIS) of the former Soviet Union.

[b]Includes Puerto Rico.

[c]Includes former Federal Republic of Germany and German Democratic Republic.

[d]Newly independent states of former Yugoslavia. Serbia and Montenegro are also referred to as Federal Republic of Yugoslavia.

[e]Newly independent states of the former Czechoslovakia.

[f]Includes former Yemen Arab Republic and People s Democratic Republic of Yemen.

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