

The Fertilizer Industry, World Food Supplies and the Environment

International Fertilizer Industry Association



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Message from the President of IFA

Government, farmers and industry - partners in food security

Mineral fertilizers, and hence the fertilizer industry, constitute, and will continue to constitute, one of the most important keys to world food supplies - though by no means the only one. The more nutrients are taken out of the soil by crops, the more have to be put back: there is no substitute for plant nutrients. And the more people there are on this planet, the more food they will eat. For reasons relating to the various nutrient cycles - but especially the nitrogen cycle - there is simply not enough organic material to sustain soil nutrient levels, and hence soil fertility - not even if all the world's animal and human excreta could somehow be collected and recycled to agricultural land.

The fertilizer industry and its associated trades comprise a complex network of suppliers and buyers of numerous different raw materials, intermediates and finished products, and this creates a high degree of international interdependence. Over the last few decades, primary production has tended to concentrate near the major sources of raw materials and feedstocks; and, as smaller sources of these materials become exhausted or uneconomic, this trend will continue, producing still greater geopolitical interdependence and division of responsibilities for the prosperous survival of planet Earth.

The responsibility of governments for ensuring food security will grow proportionately with the growth of populations; and governments in developing countries bear a special responsibility for promoting agricultural

inputs including fertilizers. They cannot do this effectively without the confidence of farmers and the fertilizer industry - all three parties are in a partnership, without which their objectives will fail.

Much remains to be done, but IFA has felt for some time that the achievements, problems and prospects of the mineral fertilizer industry deserve more widespread recognition. No-one claims that fertilizers are a panacea, or that they can do their work without other inputs - notably water. But their contribution to past and future food supplies is so important that there ought to be a better public appreciation of this.

It is for this reason that this book has been produced. It is intended as a basic introduction to fertilizers and the fertilizer industry. It is not for the experts: it is for those who want to acquire an elementary knowledge of the nature of fertilizers, their effects, the problems of promoting their use, the economics of the industry, its changing structure, its raw materials base, its future prospects. There is a little history, a small dose of agronomy and some indications on production technology.

For those who wish to delve more deeply into particular aspects, IFA and UNEP, the United Nations Environment Programme, with other partners, are preparing a series of more technical publications on the subject of mineral fertilizers and the environment.

U.S. Awasthi
Managing Director
Indian Farmers Fertiliser Cooperative Ltd (IFFCO)
India
November 1998.

Message by the Director of the UNEP Division of Technology, Industry and Economics

Sustainable agriculture, and the sound use of fertilizers to support it, is one of the important development challenges facing countries around the world. Agriculture is also closely linked to environmental quality in a variety of ways, and the challenge of our generation is how to feed a growing planet while maintaining the integrity of our ecological life-support system. We can no longer look at each factor in isolation, nor can we make decisions based on limited appreciation of the interrelations between human activities.

To make better global decisions we need a better overview of how the various elements fit together. UNEP is grateful to the International Fertilizer Industry Association (IFA) for its initiative in compiling information that allows us

to see some of the important aspects of fertilizers - their manufacture, distribution and their use. Through this book we hope that a better understanding of the issues, and a greater dialogue concerning the future of fertilizers and their environmental implications will ensue.

The book should be read in conjunction also with other publications concerning fertilizer manufacture and fertilizer application, so that a complete picture can be built up of how the various aspects of fertilizer use in agriculture fit together.

I congratulate IFA for its initiative in preparing this book, and encourage readers to respond in an open and informed dialogue in order to help the industry meet the challenge of achieving sustainable agricultural development.

Jacqueline Aloisi de Lardere

Director

UNEP Division of Technology, Industry and Economics

December 1998.

1. Feeding the crops which feed the world

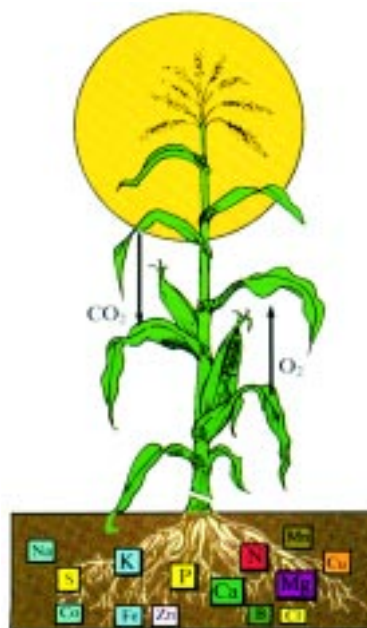
All forms of life need energy, food and water, and plants are no exception. Without water, oxygen, carbon dioxide and numerous mineral elements, they would die, and so would we. Of the minerals, plants need comparatively large amounts of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. These are called major or macro-nutrients. Numerous other elements, called micro-nutrients, are also needed in much smaller amounts. They include boron, chlorine, copper, iron, manganese, molybdenum and zinc. Leguminous crops, such as beans and peas, also need small amounts of cobalt.

Rainfall supplies the water and part of the oxygen. The atmosphere supplies carbon - as carbon dioxide - as well as the rest of the oxygen. Legumes and certain other plants can obtain part of their nitrogen from the atmosphere, but most plants must obtain almost all their nitrogen from the soil. All other plant nutrients must be obtained entirely from the soil - or from what is added to the soil by animals and man.

A deficiency of any single nutrient is enough to limit growth.



All forms of life need energy, food and water. Plants are no exception.



If the soil cannot deliver enough of any nutrient, the growth of the plant is limited. A deficiency of any single nutrient - even of one required in only very small quantities - is enough to limit growth. The most usual limitations concern nitrogen, phosphorus and potassium, followed by sulphur, but in acid soils a lack of calcium can be equally important.

Where nature is still untouched - in the rain forests of central Africa and the Amazon basin, for example - a closed nutrient cycle exists. Plant growth is limited by the available nutrients maintained in this cycle, as well as by other growth factors such as sunlight, heat and water.

When man introduces agriculture, this cycle is broken. The soil is opened up to the dangers of leaching and erosion. Without good management, irreversible damage can be done.

1. Feeding the crops that feed the world



Rainforest. Marine Park, Australia. (J. Threled, UNESCO)

Moreover, each harvest takes more nutrients away from the soil.

This loss is partly offset by the decomposition of organic matter in the soil and the gradual weathering of soil minerals. Nutrients are thereby released in forms which plant roots can take up. But this natural process is far too slow. Without an external input, the capacity of the soil to supply crops with nutrients is progressively reduced. When agriculture replaces a forest or a meadow, the soil can be exhausted after only a few seasons, if it is not properly managed. In strongly acid savannah soils which cover large parts of the tropics, a lack of calcium and other minerals such as sulphur, magnesium and zinc has reduced vast areas to virtual exhaustion even before the introduction of agriculture.

Until mineral fertilizers were commercially developed in the mid-19th century, the only way of providing a crop with more nutrients than the soil could supply was by adding human, animal or crop wastes to the land. The human population was effectively limited to what this system could support. It depended on the return of waste materials to the soil. The growth of cities during the industrial revolution led to an

increasing loss of nutrients from the natural cycle. Mineral fertilizers introduced extra nutrients into this cycle and made it possible to feed the growing urban populations.

Mineral fertilizers contain one or more of three major nutrients - nitrogen, phosphorus and potassium. They contain at least one of them. Lime, for example, is not a fertilizer: it supplies the soil with calcium, and often with magnesium, but is classed as a soil conditioner. The same is true of gypsum, which is used to carry calcium and sulphur to the soil. Sulphur is also required in large amounts - in general crops need as much sulphur as phosphorus.

It is inherently difficult to estimate the share of fertilizers in increasing agricultural output: so many interactive factors are involved. But in Western Europe, after 150 years of increasing fertilizer use, it is thought that roughly half of the present agricultural output may be attributed to fertilizers. This would not have been possible without the contribution of improved plant varieties and animal breeds, pesticides, modern farm equipment and many other agricultural advances. Conversely, the benefits of these improvements would not have been realized without fertilizers.

In tropical and sub-tropical countries, the FAO Fertilizer Programme organized hundreds of thousands of trials and demonstrations in

Deforestation in Asia. (Potash and Phosphate Institute)



1. Feeding the crops that feed the world

Nitrogen is an important component of proteins and chlorophyll. It is taken up in larger amounts than in the case of other nutrients and is usually most responsible for yield increases.

Phosphorus is primarily responsible for all processes in plant life in which energy is stored and utilized. It promotes root growth. It improves the quality of grain and accelerates its ripening.

Potassium is involved in the production, transportation and accumulation of sugars in the plant. It maintains electrical balance within the plant cell. It assists the hardiness of plants and their resistance to water stress, pests and diseases.

Sulphur is an integral component of certain vitamins and enzymes.

farmers' fields throughout Africa, Asia and Latin America. The results showed clearly and consistently that, even in traditional farming conditions, the yields of food crops can be increased by 40 - 50%, solely by using fertilizers. The FAO has stated that "after land and water, fertilizers are probably the most important input leading to increased yields. They were responsible for some 55% of the increase in yields in developing countries between 1965 and 1976."¹

Between 1961 and 1965 the world cereal area averaged 677 million hectares, and annual cereal production 988 million tonnes. The averages between 1994 and 1996 were 699 million ha and 1970 million tonnes i.e. an increase of 3% in the cereal area and 200% in the production. Increased crop yields and intensification of agriculture, of which mineral fertilizer use is an essential component, must have accounted for a large majority of this rise in food production; a typical response ratio to fertilizers is 10 kg cereals per kg fertilizer nutrients applied. It is a reasonable assumption that many millions of people in developing countries owe their survival to the introduction and use of mineral fertilizers.

It has been estimated that mineral fertilizers contribute about 40% of the nitrogen taken up by the world's crops.² Since crops provide about 75% of all nitrogen in human protein consumption - either directly, or indirectly through animals - it follows that nearly one third of this protein depends on fertilizers.³

Notes

¹"*Agriculture : Toward 2000*", (Abbreviated version of Conference document C79/24), FAO, 1981, p.66.

²Smil, V., *Global Population and the Nitrogen Cycle*, Scientific American, July 1997.

³i.e. 0.4 x 75%.

Saracollé women working in fields. Sub-Saharan Africa.



2. A historical perspective

When Thomas Malthus published his *Essay on the Principle of Population* two hundred years ago, it seemed self-evident that human population growth would be periodically checked by famine, if not by pestilence and war. Despite 18th century hopes for the “perfectibility” of man and for a brave new “scientific” world, where the application of reason would diminish the incidence of war and enhance the ability of medicine to defeat pestilence, it was impossible to see how agricultural production could be expanded sufficiently rapidly to accommodate the exponential nature of unconfined population growth. But two hundred years ago, the roles of nitrogen, phosphorus and potassium were unknown, and the science of plant nutrition was still dominated by ideas which were originally formed by the ancient Greeks.

At that time, animal manure still provided a very large majority of nutrient restitution to the soil and, together with good cultivation and weeding, it was the key to increasing crop yields. But more animal manure meant more and better animals, and this, in turn, meant more grassland and feeding stuffs, both of which made inroads on the potential areas available for human food crops. There were obvious limits to the amount of animal manure which any country could put on its arable land. These limits would not have been so important, if social constraints in much of the world had not limited the recovery and use of human wastes.

Whole civilisations have disappeared through diminishing soil fertility. Justus von Liebig, to whom we owe the original vision of an agriculture sustained by chemistry, attributed the fall of the Roman Empire largely to diminishing soil fertility. The Sumerians of

ancient Mesopotamia and the Mayans of Central America are other examples.

On the other hand, in China the peculiar nature of rice cultivation and a determination to recycle every scrap of organic waste, enabled the lowland Chinese to support a growing population for thousands of years - but at the cost of devastated uplands, widespread endemic diseases, periodic famines, and great poverty and misery. As late as 1949, organic manures provided China with more than 98% of nutrients restored to the soil, and the rice yield of about 700 kg/ha had varied little over centuries. Today, the proportion is less than 38%, and the average rice yield is nearly 6000 kg/ha.

India’s experience of famine dictates an active, costly promotion of fertilizer use. Millions starved to death in West Bengal as

Tikal, Guatemala. (UNESCO/INGUAT - SANJOA)



2. A historical perspective



Rice paddies. Xingping, Guagxi, China.

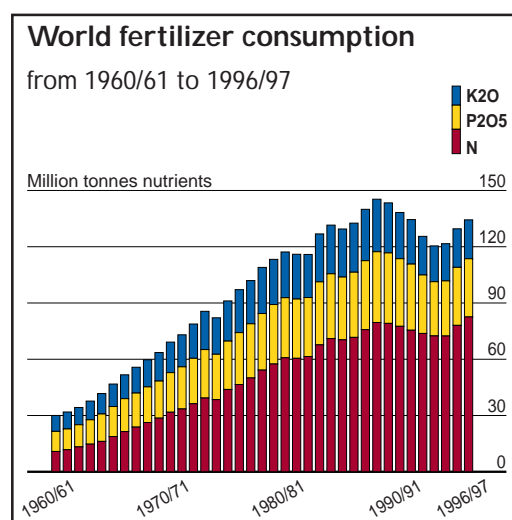
recently as 1943. At the end of the 19th century, more than six million people died in two successive famines. In the mid-1960s, a succession of monsoon failures caused many observers to despair of India's prospects. Like Malthus, they were unable to envisage the revolutionary technologies which were even then emerging from agricultural research.

Without the "Green Revolution", disaster would undoubtedly have struck India long before now. By 2025, India's population could increase by nearly 40% over its mid-1990s level. Allowing for increased per capita food demand, it is estimated that this will necessitate an annual grain supply of about 300 million tonnes, compared with about 190 million tonnes in 1996. Since further agricultural land expansion is not feasible, farming intensity and average crop yields must be considerably increased, if large food imports are to be avoided.

In Europe, growing populations gradually ate into forestland, converting it to arable and pasture. Crop yields were initially sustained by widespread fallowing, allowing the land time to

recover from previous crops. But this kept more than one third of arable land out of cultivation. As population density increased, farmers discovered that leguminous crops could be grown on the fallow without harming the yields of the subsequent cereals. This practice was not new. In fact, it was known and recommended in Roman times, but not widely adopted in Europe until the 18th century. Leguminous crops accumulate nitrogen in their residues. Perhaps even more importantly in the pre-modern context, they provided a large addition to animal feed, enabling more animals to be wintered under shelter and greatly adding to the supply of manure. Root crops, especially turnips, did the same. Crop rotations of cereals - legumes - root crops were an essential means of maintaining a minimum of food sufficiency in much of Europe. Nevertheless, persistent food shortages caused much misery and played a large part in triggering the French Revolution. Throughout the 19th century, there was growing reliance on grain imports from the Americas, Eastern Europe and elsewhere.

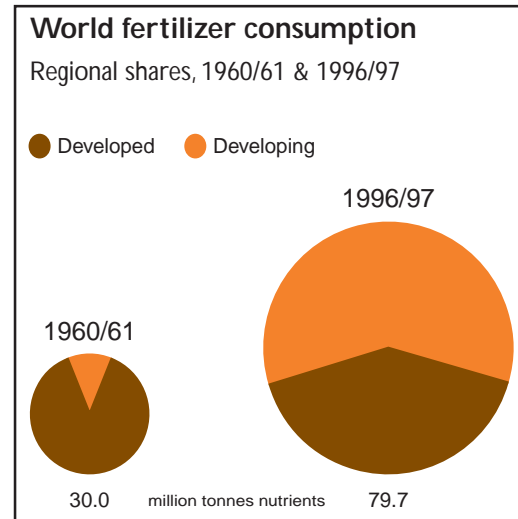
In North America, for much of the 19th century land was so cheap and plentiful that, over vast areas, manuring was not economic. Settlers tended to prefer to deplete soil fertility and then move on. By the 1930s, large areas of



2. A historical perspective

the middle west of the USA were reduced to semi-infertility and became “dust bowls”. Subsequently, with improved technologies and better understanding of soil processes, fertility was rebuilt. The Tennessee Valley Authority was instrumental in resolving these problems. Crop yields in these areas are now similar to naturally more fertile soils in adjacent areas. The proper application of fertilizers has played a large part in this restoration.

The discovery of the true nature of plant nutrition in the first half of the 19th century led directly to the birth of the fertilizer industry. First came the manufacture of superphosphate in the 1840s, followed by the growing use of by-product ammonium sulphate from the gas industry, basic slag from the steel industry, and sodium nitrate from Chile. The discovery of large deposits of potash and phosphate rock provided further essential mineral resources. Finally, in the first two decades of the 20th century, an economic means of synthesising



ammonia was developed, thereby enabling the manufacture of nitrogen fertilizers directly from atmospheric nitrogen. For the first time in human history, farmers were released from natural constraints on plant nutrition.

3. A review of environmental events

The “environmental movement” is a term often used to describe the activities of a growing sector of society to spread an appreciation of the negative impact of human activities on the natural environment, and a general increase in activities designed to reverse such trends. Although the roots of the movement can be traced back to the beginnings of the wilderness societies and the establishment of national parks in the United States and Europe, it is widely acknowledged that the importance of environmental issues in mainstream politics gained momentum during the 1950s and 1960s. This coincided with periodic social unrest caused by anti-war protests and a general mobilization of youth and student campaigns, particularly in the United States, coupled with a general increase in prosperity, leisure time and mobility in industrialized countries. The role played by television and the provision of education and other social services is also not to be underestimated.

Observers also point to the publication of Rachel Carson’s “Silent Spring” in 1962 as a milestone which captured the attention of many on the road to environmental consciousness. Another was the polemic “The Population Bomb” by Paul Ehrlich in 1968. The apparent uncontrolled exploitation of natural resources, especially fossil fuels, was promoted by pressure groups as a shock tactic to drive public opinion, together with images of starvation and desertification in parts of Africa and South Asia. The National Environmental Policy Act in 1969 in the USA required that all government-sponsored developments be first assessed for their environmental impact. The Council of Europe designated 1970 as European Conservation Year, and one of the first major

international conferences to focus on environmental issues was the Stockholm Conference in 1972. The oil crisis in 1973 brought energy and resource issues to the top of the world political and economic agenda.

During these first two or three decades of widespread environmental concern, attention was generally drawn to more localized incidents, often associated with pollution from heavy industry, mining operations, factories, and other highly visible, large scale activities. It was also a period which spawned several high profile environmental campaign groups, stimulated by emotive protest campaigns to halt the activities of whale hunting, seal clubbing and the demise of elephant and other large game populations in Africa.

The 1980s saw the evolution of the environmental movement from its confrontational roots into a more mature philosophy, which sought to promote the concepts of responsible individual, collective and corporate citizenship, with sustainable resource use while retaining economic growth and development. 1988 was designated European Year of the Environment, and several significant reports laid the foundations of modern environmentalism, the most important of which was the 1987 report of the Brundtland Commission.

However, as it became clear that the accumulated sum of local pollution was leading to hitherto unexpected profound damage to the global environment, governments became more interested in addressing the wider environment in a more coordinated fashion, and the United Nations provided the platform for a series of international conferences which have attempted to define a strategy to achieve “environmentally sustainable development”. For the first time,

these fora brought together representatives from governments, environmental organizations and the industrial sectors, to focus on the fundamental humanitarian issues of population, environment, agriculture and climate.

The United Nations Conference on Environment and Development (UNCED), the “Rio Earth Summit” of 1992, the Social Summit in 1995 and the World Food Summit in 1996 have each defined objectives and outlined action plans to alleviate poverty, feed people, protect the environment and maintain natural resources for future generations. The official product of UNCED (the Rio Earth Summit) resides in several agreements, which have essentially laid the environmental agenda for several decades, including the Framework Convention on Climate Change, the Convention on Biological Diversity, and Agenda 21. Agenda 21 is an immense document of 40 chapters outlining an “action plan” for sustainable development.

UNCED has established an ongoing instrument under ECOSOC - the Economic and Social Council of the United Nations and an Interagency Committee - to monitor progress toward achieving the objectives agreed in UNCED Agenda 21. This UN Commission for Sustainable Development (CSD) meets each year to examine these chapters under sectoral themes, which include land resources, forests and sustainable agricultural and rural development.

The subjects of other post-UNCED conferences include:

- Sustainable development of small island developing states (Barbados, 1994)
- Population and development (Cairo, 1994)
- Social development (Copenhagen, 1995)
- Women (Beijing, 1995)
- Human settlements (Istanbul, 1996).

3.1. The fertilizer industry and the environment

The fertilizer industry has a two-fold impact on the environment, arising from the emissions during production and from losses as a result of their use.

As regards the production of fertilizers, there has been considerable progress during the past thirty years. The improvements in the efficiency of energy use are indicative. Most of the energy consumed by the global fertilizer industry, almost 93%, is used in the manufacture of nitrogen fertilizers. G. Konshaug^{3b} has reported calculations, based on today’s fertilizer production level of 134 million tonnes total nutrients, comparing theoretical energy consumption using best practices known in 1968 and those of 1998.

Best Available Techniques, BAT	Global Energy Consumption Per Year
BAT in 1968	5040 GJ
BAT in 1998	2743 GJ

Present energy consumption by the fertilizer industry is estimated at 4400 GJ, some regions being substantially more efficient than others. (Total world energy consumption for all purposes is estimated at 360 000 GJ). A reduction of energy consumption in the fertilizer industry is accompanied by an even greater reduction in greenhouse gas emissions.

Also in the case of fertilizer use, there have been considerable improvements in efficiency, at least in the developed countries, as measured by crop output obtained per unit of fertilizer nutrient input. However, also in the case of fertilizer use, there are considerable differences between regions. From its beginnings, over 150 years ago, the fertilizer industry has been research-based. Farmers in developed countries are reasonably receptive to improved practices.

3. A review of environmental events

But since 1960 there has been a large number of new users in developing countries. The advisory task is formidable. Whereas there are about 400 basic fertilizer producers in the world, there are perhaps two billion farmers.

Concern about the impact of fertilizer use on the environment is fairly recent. Up to the early 1980s, few questioned their benefits and their importance. In the mid-1970s there was near panic at inter-governmental level when a global shortage of fertilizers was feared.

But by 1990, mineral fertilizers had become unpopular. The speed with which public opinion turned against fertilizers took the industry by surprise. Perhaps the development had started in the 1970s, when the eutrophication of inland waters, due largely to phosphate pollution, became a recognized problem. Eventually the blame was attached mainly to phosphate-based household detergents. As a result of regulatory measures, which reduced the use of phosphate-based detergents and led to the installation of waste water treatment plants, the enrichment of inland waters with phosphates was greatly reduced, and pressure on fertilizers relaxed.

Two important milestones in the development of public awareness of the environmental impact of agriculture were the reinforcement of water quality regulations in many countries in the 1980s. Then, in 1991, the European Commission (EC) Nitrate Directive was agreed. Implementation of these measures has resulted in a much closer surveillance of the nitrate content of drinking water and, through the media, examples of high nitrate levels came to the attention of the general public.

The occurrence of undesirable concentrations of plant nutrients in surface and underground waters has been accompanied in many Western European countries by estimates indicating that the amount of plant nutrients applied considerably exceeds the removal by crops in certain regions. Most of the excess nutrients come from intensive livestock operations, which have a waste disposal problem, but fertilizers are also implicated.

In addition mineral fertilizers, although they are growth enhancers, are often wrongly associated with plant protection products which are the subject of deep concern. At the same time, mounting, expensive agricultural surpluses in West Europe fueled the criticisms.

In Europe, large areas of the Baltic and North Sea coastlines and areas of the Mediterranean sometimes suffer from eutrophication due to nitrates. In the USA, nitrates and phosphates are suspected of causing eutrophication in the Gulf of Mexico, Chesapeake Bay and elsewhere. It is unlikely that mineral fertilizers are primarily responsible for this eutrophication; livestock wastes are much more likely culprits. But fertilizers contain the nutrients which are responsible, and are therefore prime suspects.

The Kyoto Protocol adopted in December 1997 during the Third Meeting of the Conference of Parties of the United Nations Framework Commission on Climate Change established an obligation on countries which ratify the Protocol to reduce the overall emission of greenhouse gases by at least 5% below 1990 levels in the commitment period 2008 to 2012. Six gases are covered, two of which are particularly relevant to the fertilizer industry; carbon dioxide, CO₂, and nitrous oxide, N₂O. Another gas, methane, CH₄, is also included. Ruminant animals and rice paddies are important sources of methane but a direct link with mineral fertilizers has not been established.

Carbon dioxide is an unavoidable by-product of the manufacture of ammonia. Nitrous oxide is released during the production of nitric acid, in the manufacture of ammonium nitrates.

The environmental aspects of fertilizer production and use are discussed in more detail in chapters 12 and 13.

Note

^{3b} G. Konshaug (1998) "*Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production*", IFA Technical Conference, Marrakech, Morocco, September/October 1998.

4. The fertilizer producers and their products

The world mineral fertilizer industry is extremely heterogeneous. Among the largest producers, are some giants of the chemical industry in all parts of the world - companies with sales measured in billions of dollars. Producers of the main raw materials for fertilizer production form an important part of the petrochemical and mining industries. At the other extreme, there are many small enterprises which have no primary chemical production at all: they buy all their materials to make mixtures or blends, which are often termed “compound” fertilizers.

In the 1970s and 80s, the geographical balance of the industry shifted strongly towards the former communist economies and the developing countries. The communist countries pinned their faith on fertilizers to spearhead the modernization of their agriculture and improve their poor crop yields. The developing countries viewed fertilizers as a strategic necessity to combat the threat of famine in a situation of rapid population growth. Those with abundant natural gas, phosphate rock or potash saw

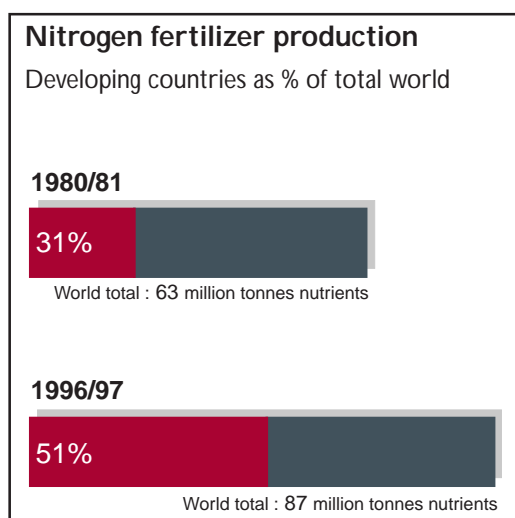
fertilizer production as a primary means of economic development. Finance from lending agencies such as the World Bank was often available on favourable terms.

All this led to a rapid growth of production capacity and a sharp increase in state ownership. In the 20 years from 1965 to 1984, the share of state enterprise in the world ammonia industry rose from 30% to 64%. In the potash industry, it rose from 40% to 65%, and in the phosphoric acid industry, from 10% to 46%. Similarly, by the mid-1980s, nearly 60% of world phosphate rock production was state-owned.

The collapse of the Soviet Union and the strong privatization movement of the 1990s reversed this trend. In Russia and throughout Eastern Europe, the withdrawal of state ownership and the reduction or elimination of heavy subsidization of both industry and agriculture led to a large fall in the production and consumption of fertilizers, and the industry was largely transferred into private or semi-private hands. Moreover, a worldwide excess of production capacity, the trend towards industrial globalization, and continuing competition from state-owned, or state regulated enterprises in numerous developing countries, notably India and China, obliged the private sector to concentrate its resources. This led to widespread plant closures, numerous company mergers and acquisitions, and massive restructuring.

Mineral fertilizers are mainly produced from a small number of distinctly different raw materials and intermediate products. Some of these are also used directly as fertilizers. The main raw materials are energy, mineral phosphate, potassium salts and sulphur.

The main source of energy is natural gas and other hydrocarbon materials. Natural gas also



4. The fertilizer producers and their products

provides a large proportion of the world supply of sulphur, since many commercial gas deposits are “sour” and the gas cannot be used until the sulphur has been removed. Phosphate rock and potassium salts are mined in various parts of the world. Some elemental sulphur also is mined but today most sulphur is recovered sulphur from oil refineries, iron and copper pyrites and by-product sulphuric acid.

Using these raw materials, the number of chemical process routes to the finished products is relatively small. But at the end of the production chain a great diversity of final products appears.

Each product has its own advantages for a particular crop, soil and climate. It may be solid or fluid. Solids may be either chemically homogeneous particles or mixtures (blends) of different products. Fluids may be salt solutions or suspensions of solid particles. They may even take a gaseous form, as in the case of the injection of anhydrous ammonia directly into the soil - a widespread practice in the USA and a few other countries.

The content of nitrogen, phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) in a fertilizer forms the main basis of its commercial value. It may also contain other macro-nutrients such as calcium, sulphur, and magnesium, as well as micro-nutrients like boron, iron, manganese and zinc, and these also affect its value.

In 1996, the world fertilizer industry produced about 80 million tonnes⁴ of nitrogen, 33 million tonnes of P_2O_5 and 23 million tonnes of K_2O - a total of 136 million tonnes of primary plant nutrients which were contained in about 325 million tonnes of the various finished products, with a sales value of about 50 billion US dollars.

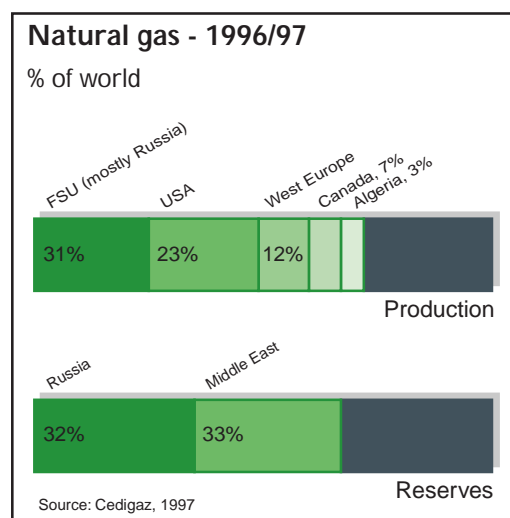
Nitrogen fertilizer production is based mainly on the synthesis of ammonia from atmospheric nitrogen and the hydrogen in hydrocarbons. In the case of phosphate fertilizers, nearly three quarters of the world production of P_2O_5 is

based on phosphoric acid, which requires large amounts of sulphur in the form of sulphuric acid, in order to convert the P_2O_5 in phosphate rock to a largely water soluble form. Ammonia, phosphate rock, potash and sulphur have many other industrial uses apart from fertilizers, but the fertilizer industry consumes most of their production. Consequently, the geographical structure of the fertilizer industry is not only governed by the location of its markets but also by the location of commercial sources of these raw materials and intermediates.

4.1. The nitrogen industry

4.1.1. Ammonia

The development of technology has also played a historic role in the development of this geographical structure. Thus, the early technology for ammonia synthesis was developed in Western Europe, using cheap electricity or coke-oven gas as the feedstock. At that time, these feedstocks were available only in the industrialized countries. Subsequently, processes were developed involving the gasification of heavy fuel oil and the reforming of steam and naphtha. A substantial part of the ammonia industry in the industrialized countries came to be based on naphtha and fuel oil. It was



4. The fertilizer producers and their products



Ammonia Unit. Netherlands. (Hydro Agri Europe)

this part of the industry which was suddenly rendered much less competitive by the first oil crisis in the mid-1970s.

Fortunately for the economics of nitrogen fertilizer use, the steam-reforming process had already been adapted to use natural gas. In fact, most new plants from the mid-1960s onwards were built to use natural gas. This enabled a number of developing countries with very low-cost gas, often associated with oil production, to develop large ammonia industries which compete successfully with those in the developed countries.

Similarly, the countries of Eastern Europe and the former Soviet Union (FSU) developed a very large ammonia industry between 1970 and 1990, nearly all of which was based on natural gas.

4.1.2. Nitrogen fertilizers

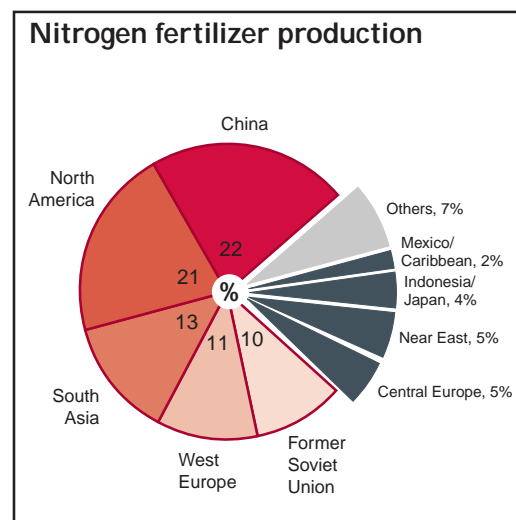
The first nitrogen fertilizer to be commercialized was sodium nitrate⁵, mined from natural deposits in Chile and imported into Europe and America from about 1830 onwards. Next came ammonium sulphate. This was initially obtained as a by-product of the coke industry, which was developed to provide gas for street lighting and to serve the expanding steel industry in Europe and America in the 19th century.

By 1900, it was apparent that, without a technology for fixing nitrogen from the

atmosphere, food supplies would be insufficient for the growing populations of the industrialized countries. By 1905, the idea of passing air through an electric arc was successfully developed in Norway to produce nitric acid and calcium nitrate. About the same time, calcium cyanamide was produced by reacting lime and coke in an electric furnace. However, both these processes were soon outdated by the discovery of a technology to synthesize ammonia from atmospheric nitrogen and hydrocarbons. This was to revolutionize the nitrogen fertilizer industry. The first commercial plant using this process began to operate in Germany in 1913.

Initially, fertilizers took only a minor share of this new source of fixed nitrogen, because it was quite costly and there were higher-value industrial uses. But the age-old agricultural dependence on organic manures and the relatively rare sources of mineral nitrogen compounds had been broken.

The early nitrogen fertilizers - mainly ammonium sulphate, calcium cyanamide and calcium nitrate - contained what, by modern standards, were relatively low concentrations of nitrogen (N), in the range of 15 - 21%. The next step was to produce more concentrated products. However, it was not until the 1940's that ammonium nitrate, with about 34% N, and calcium ammonium nitrate, with up to 27% N,



4. The fertilizer producers and their products

became important fertilizers. By the 1960's they had become the leading nitrogen fertilizers.

Today, the world's cheapest and most common nitrogen fertilizer is urea. Containing 46% N, it is more economic to transport over large distances than less concentrated materials. It is produced by reacting ammonia and carbon dioxide, thus making use of the large amounts of by-product carbon dioxide produced by ammonia plants. Consequently, urea plants are always located together with ammonia plants.

As in many other industries, the cost of fertilizer production is strongly influenced by economies of scale. Over the last 40 years, aided by various scientific advances, the engineering industry has been able to increase the practical economic size of ammonia and nitrogen fertilizer plants by a factor of 5 or more.

Thus, four powerful forces have radically shifted the geographical distribution of production over the last 35 years:

- the growth of population in the developing countries;
- the increased use of products like urea;
- the increased economic size of ammonia and associated fertilizer plants;
- the large scale exploitation of cheap natural gas in Eastern Europe, the FSU, China and numerous countries of Asia, Latin America and the Near East.

The OECD countries accounted for 73% of world nitrogen fertilizer production in 1960 but the same group⁶ had only 37% share by 1995. The former Communist countries of the Soviet Union and Central Europe had only 16% in 1960, but by the mid-1980s this had risen to 30%, only to fall back to 10% by the mid-1990s. The developing countries taken together (market and planned economies) had only 10% in 1960 and now have well over 50%. Population pressure and food requirements will ensure that the share of the developing countries will continue to grow.

4.2. The phosphate fertilizer industry

The industrial technology for phosphate fertilizers preceded synthetic ammonia by at least 70 years. It was very simple. Starting with bones as the source of phosphate, and later using finely ground phosphate rock, dilute sulphuric acid was added to convert the phosphorus in these materials to a water soluble form. The product was called "superphosphate". The first sustained commercial production began in England in 1843. Over the next 30 years, factories sprang up all over Europe and in the southern and eastern parts of the USA.

Like the early nitrogen fertilizers, superphosphate had a low nutrient concentration - typically 16 - 20% P_2O_5 . To increase the P_2O_5 content, the use of phosphoric acid in the chemical reaction was essential. The production of phosphoric acid began in Europe in the 1870's, and this led immediately to the manufacture of superphosphates containing two or three times more P_2O_5 . These products became known as enriched or triple superphosphates.

Ordinary superphosphate - the less concentrated variety - continued to dominate the world phosphate fertilizer market until the 1950's. It still accounts for nearly 20% of the

Drag-line extracting phosphate rock. Khouribga, Morocco. (Groupe Office Chérifien des Phosphates)



4. The fertilizer producers and their products

P_2O_5 in world fertilizer production and is an important phosphate fertilizer in regions as diverse as China, Australia and New Zealand. In particular, its popularity in numerous developing countries is due to its simplicity of production, its low plant investment cost and, not least, its sulphur content.

The importance of triple superphosphate was slow to develop, emerging as a major fertilizer only in the 1930's. The large scale development of the phosphoric acid industry did not occur until after 1950.

Meanwhile, back in the 1880's, the development of the basic steel making process had given rise to large amounts of by-product slag - basic slag, as it was called. Certain sources of iron ore contain significant amounts of phosphorus which, if transferred into the refinery product, harm the quality of the metal. The basic steel process left this phosphorus in the slag; and this often contained almost as much phosphorus as ordinary superphosphate, although in a less soluble form. Until oxygen steel making processes gradually strangled the supply of basic slag, this by-product provided a substantial part of Europe's phosphate fertilizer supply.

Processes involving the reaction of phosphate rock with *nitric* acid, instead of sulphuric acid,

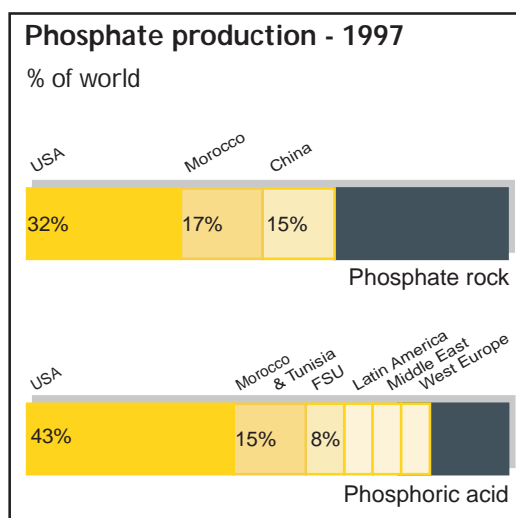
also gained popularity, particularly in Europe. The resulting products are known as nitrophosphates.

In America, the phosphate fertilizer industry also developed from many small, widely dispersed superphosphate producers. Gradually, with the large scale development of phosphate deposits in Florida and, more recently in North Carolina, and with improvements in phosphoric acid technology, the industry concentrated in these two states. Since triple superphosphate contains over 40% more P_2O_5 than phosphate rock, its shipment is more economic than that of phosphate rock. This, together with the mining of large, economical sulphur deposits in the US Gulf area, enabled the American phosphoric acid industry to compete successfully with ordinary superphosphate manufacturers over large distances and led to a growing export trade.

The development of the ammonium phosphate industry in the 1960's assisted this process. The product of the reaction of ammonia and phosphoric acid had been known long before the 1960's, but it was not until then that circumstances became favourable for its large scale production and use. Although superphosphates and nitrophosphates continue to be very important in several large national and regional markets and have a substantial share of world trade, ammonium phosphates are now the leading form of phosphate fertilizer.

Economic access to phosphate rock and some form of sulphur has always governed the geographical concentration of the phosphate fertilizer industry. In the 19th century, the industrial revolution provided a ready supply of sulphuric acid. This, together with the development of the rich phosphate deposits of Florida, South Carolina and what was then French North Africa, provided the main basis for the superphosphate industry in Europe and America.

Many phosphate deposits have been discovered over the past 50 years. In only the



4. The fertilizer producers and their products

last decade, China has emerged as the third largest producing nation. Indeed, only three countries - USA, China and Morocco - account for almost two thirds of the world supply of phosphate rock. Morocco alone accounts for one third of international trade in phosphate rock.

These same three countries also account for over half of the world production of primary processed phosphate fertilizer materials. Although the share of Morocco in the latter is still small, this country accounts for no less than 40% of world trade in phosphoric acid. Several other newly industrializing countries are also major participants in world trade in processed phosphate fertilizer materials.

The manufacture of every tonne of P_2O_5 in phosphoric acid requires nearly a tonne of sulphur in some form or other. Only 3 countries - USA, Canada and China - account for half of world sulphur production in all forms. The major traded form of sulphur - brimstone, or elemental sulphur - accounts for two thirds of total sulphur production, and the USA and Canada account for half of world brimstone production. Canada takes nearly 40% of the world brimstone trade.

The concentration of phosphate rock and sulphur resources in comparatively few countries has lessened the regional shift in phosphate fertilizer production. Whilst the discovery of low cost natural gas in numerous developing economies dispersed nitrogen production to countries which, until comparatively recently, had little or none at all, phosphate rock and sulphur production capacity has largely remained concentrated in countries which were already the main suppliers 25 years ago. Notable exceptions are China for phosphate, and certain Middle Eastern oil and gas producers for sulphur.

The developed market economies' share of world phosphate fertilizer production has declined over the last 35 years from 85% in

1960 to 45% in the mid-1990s. The share of North America in the supply of the essential raw materials - phosphate rock and sulphur - has ensured that this share remains higher than in the case of nitrogen. The countries of the FSU, which had nearly a quarter of world phosphate fertilizer production⁷ in the mid-1980s, saw this share decline dramatically to 8% by the mid-1990s. The developing countries' share has risen from 7% in 1960 to 46% in 1995, i.e. roughly the same as the developed market economies (not including the FSU).

4.3. The potash industry

Before the mid-19th century, the agricultural need for potassium was well recognized. Wood ash was the chief source. In 1859, a deposit of potash salts at Stassfurt in Germany was discovered, and the first potash mine was opened there in 1862. This and other German deposits dominated the potash market for 75 years.

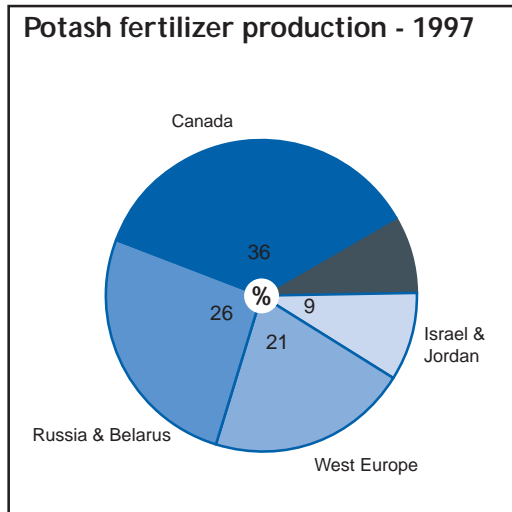
Low-grade, unrefined ores were the first products. None contained more than 25% K_2O . The development of refining methods led to higher concentration. Potassium chloride, with 60 - 62% K_2O , is now the main product.

The chloride form of potassium, though accounting for an overwhelming share of the potash market, is not so acceptable for certain

Potash mining. Esterhazy, Saskatchewan Facility, Canada. (Potash Corp. of Saskatchewan Inc.)



4. The fertilizer producers and their products



crops as the sulphate or nitrate forms, but the latter are more costly and are used only in particular circumstances.

Large potash deposits were eventually found in other countries. Production started in France in 1910, in Spain in 1925, in the former Soviet Union and USA around 1930, in Canada in 1960, in Italy in 1964 and in the UK in 1974. Italy has ceased production, and reserves are low in France and Spain. Belarus and Russia are

now large producers. Israel developed a large potash recovery operation from the brine of the Dead Sea in the 1960s⁸, and Jordan followed suit in 1982. A similar operation exists in the USA at the Great Salt Lake, Utah. In Latin America, Brazil and Chile have small potash industries.

Twelve countries account for over 99% of world potash production. The developing countries have only 6-7% of this production, and over half of this comes from Jordan. Almost all have to import their entire requirements.

Notes

⁴tonnes refer to metric tonnes throughout this publication.

⁵unless one counts saltpetre, which was occasionally used agriculturally from at least biblical times onwards, but which was far too expensive for such use, once it was used to make gunpowder.

⁶i.e. developed countries excluding the former Communist countries for the sake of statistical comparability.

⁷including ground phosphate rock for direct application.

⁸The first potash refinery at the Dead Sea was built in 1940.

5. The cost of fertilizers

On the demand side there is the relationship between fertilizers and food supplies. Even in highly developed countries, the price of food is one of the most sensitive political issues. It is all the more so in countries where food takes over half of the household income.

On the supply side, fertilizer materials pass along a chain from the raw materials producers through the chemical processors and distributors to the farmers. Within this chain of enterprises there are also various transporters and other intermediaries. At least one of the links in the chain - and probably several - is likely to be international. All these enterprises must perceive a worthwhile financial profit from their involvement, unless their financial performance is managed or underwritten by governments for political reasons.

The profitability of the fertilizer industry depends on a combination of circumstances, all of which can vary considerably both in time and place, viz. the cost of investment, the cost of energy and raw materials, the cost of transportation, marketing and distribution, and the selling price of the products. In America in

Investment costs depend on the infrastructure, site location, etc. Potash plant and port, Canada. (Potash Corp. of Saskatchewan Inc.)



the mid-1980s, an average selling price of around US\$ 150/tonne corresponded to a return in the range of 0 - 10%, whereas in the mid-1990s, the same price gave a return in the range of 10 - 20% - a change which is largely attributable to a general decrease in the cost of energy and raw materials. The selling price is particularly variable.

5.1. The cost of investment

The cost of investment in a modern, large-scale primary fertilizer complex runs into hundreds of millions of dollars. Moreover, this cost varies significantly from site to site. For the same type and size of plant, the cost at a remote, undeveloped site in a developing country could be double that at a developed site in an industrialized country. It can also vary considerably according to the chosen process and the workloads of contractors and equipment vendors. In the case of ammonia, the choice of feedstock is also critical. For example, if, for reasons of availability, coal is chosen, the plant investment cost could easily be twice the cost of a similar plant based on natural gas.

The cost of infrastructure is a major factor. This infrastructure will typically include such features as roads, port facilities, rail access, housing, social services and local industries to supply equipment and services. However, since this infrastructure often serves not only the fertilizer plant but the development of the whole local economy, state subsidization is often justified.

Any lack of local experience, skills and facilities at a new construction site also tends to make plant construction inherently more costly. Under such circumstances, plants sometimes fail to achieve the consistently high operating rates

which are all the more important when the capital investment is comparatively large. Low operating rates can have a drastic effect on profitability.

Notwithstanding, numerous developing countries now have large, long established fertilizer industries at sites with developed infrastructures, and some have the advantage of very low energy and raw materials costs, abundant reserves, and proximity to growing markets. As investment costs at such locations approach those in developed countries, they are likely to capture the bulk of future investment in the industry.

5.2. The cost of energy and raw materials

Where investment costs are high, competitive production requires this disadvantage to be offset by lower costs for other inputs - energy, raw materials, transport and marketing.

The cost of energy, mainly in the form of natural gas, is of critical importance in the manufacture of ammonia and nitrogen fertilizers. The cost of natural gas is by far the most important element in determining the cost of ammonia, which in turn dictates the cost of nitrogen fertilizers. Between 1990 and 1996, in the USA the cost of gas accounted, on average, for two thirds of the total production cost of ammonia.

In the case of phosphate fertilizers, energy takes only a minor share of the production cost. Triple superphosphate, TSP, 45% P_2O_5 , is produced by acidulating phosphate rock with phosphoric acid, which in turn is produced by the acidulation of phosphate rock with sulphuric acid. To produce a tonne of TSP, about 1.3 to 1.6 tonnes of phosphate rock is required depending on the grade of rock. A tonne of TSP requires about 0.35 tonnes of phosphoric acid (100%). Phosphoric acid requires nearly a ton of sulphur for each tonne of P_2O_5 produced. Consequently, the production cost of TSP depends largely on the cost of phosphate rock

and sulphur. Apart from the variability of the market prices for phosphate rock and sulphur, local circumstances are also very variable. In the case of sulphur, for example, many phosphate fertilizer manufacturers can use by-product sulphuric acid from other processes, at a very economic cost.

In short, the circumstances affecting the production cost of any fertilizer can vary widely from location to location, even within the same country.

5.3. The cost of transport and distribution

The geological, technical and economic factors which have led to the concentration of production in larger units and in particular areas have also caused world trade to grow faster than production. The growth of fertilizer demand in Africa, Asia and Latin America has also stimulated world trade. Large volumes of bulky materials have to be transported internationally, often from one side of the world to the other.

It is difficult to be precise about the relative importance of transport costs. Once again, circumstances differ enormously. Compare the case of a land-locked country in the middle of Africa with no local production of its own and a European country, for example, where the majority of farmers are never far away from a local source. In West Europe it has been

Handling of fertilizers. Brazil. (Adubos Trevo S.A.)



5. The cost of fertilizers



Fertilizers are often stored in bulk. Thailand. (Thai Central Chemical Public Company Ltd)

estimated that logistical costs, including handling, transport and storage, represent about 20% of the price paid for fertilizer by the farmer. A 1992 case study in Ghana, with relatively favourable communications compared with many other African countries, showed that the distribution cost accounted for 50% of the retail price.

Once the fertilizer is ready to be delivered into the domestic marketing system, several cost elements other than transport affect its delivered cost. These include packaging, storage, credit, sales promotion and the margins for the dealers and distributors.

5.4. The cost of fertilizers to the farmer

In many developing countries the need to promote the efficiency of local agriculture is a strong and permanent part of government policy. In developed countries, the problem of agricultural surpluses may seem as if the pursuit of agricultural efficiency has been too successful. But surplus production is not necessarily the result of agricultural efficiency. Surplus production is a matter of costs *and* prices - and, above all, of government agricultural support policies. Agricultural efficiency is certainly concerned with reducing costs, but also with reducing the need to subsidize the farmer's standard of living, with protecting the rural environment and with reducing the cost of food

to the consumer. The efficient use of fertilizers has served - and will continue to serve - all these objectives.

In developing countries, the problem is rarely one of surplus. The governments of most of these countries are conscious of the importance of their local agriculture. Where the cost of fertilizer would normally be too high for their farmers, many of these governments introduced fertilizer price and credit subsidies, sometimes in addition to subsidizing their domestic fertilizer production.

In the 1980s, the rising fertilizer subsidy burden in a number of countries caused considerable concern, and most Asian countries have subsequently tried to reduce or eliminate some fertilizer subsidies. They have found that the political price of such action is high, especially where imports must be financed with depreciating currencies. In India, the fertilizer subsidy increased from US\$ 418 million in 1981/82 to US\$ 2446 million in 1990/91, and subsequently reduced to about US\$ 2000 million as certain subsidies were curtailed. Such is the importance of fertilizers to India. It has to be taken into account that although today no developed country subsidizes fertilizers directly, most of them subsidize agriculture itself very heavily.

What counts with the farmer is the expected return from his investment. The price of

At the end of the chain stand the farmers alone.



fertilizer can be high if the price obtained for the produce is also high. It is the ratio between the two which is important, together with the amount by which the fertilizer increases the yield of the crop. In most countries of Africa, Asia and Latin America, there is little scope for increasing real agricultural prices. Thus, a reduction of fertilizer subsidies can have an adverse effect on fertilizer use if not counter-balanced by some other factor. This represents a real challenge for the agricultural marketing,

credit and extension services in the countries concerned.

Regrettably, not all governments have supported the development of their agricultural productivity with the same commitment as is visible in the larger countries of Asia and Latin America. In some countries, a bias in favour of urban interests has sometimes resulted in distortions which tend to depress local agriculture and aggravate national economic difficulties in the longer term.

6. The international market

6.1. International trade

The first half of the 1990s was marked by a severe decline in global fertilizer demand. From 143 million tonnes of nutrients in 1989/90, consumption had fallen to 120 million tonnes by 1993/94, but has subsequently recovered to about 130 million tonnes in 1996/97. The principal reason for this decline was the collapse of the former Soviet Union and its client regimes in Central Europe. In these two regions, fertilizer use fell by more than two thirds, taking 23 million tonnes of nutrients out of global demand and thus accounting for the entire world decline. In addition, agricultural surpluses and lower crop prices in Western Europe resulted in a fall of almost 5 million tonnes of nutrients in this region over the same period. In the global context, this was offset by the continuing rise of consumption in the developing world.

The **developing countries** are all too often treated as a single group. This can be quite misleading. In the context of the international fertilizer market. Three main groups of countries should be distinguished:

- those with large domestic markets and growing fertilizer industries. These include Brazil, China, India, Indonesia, Mexico, Pakistan and several others.
- those with small domestic markets and growing fertilizer industries based on local raw materials and aimed at the export market. These include numerous Arab countries of the Middle East and North Africa, as well as Senegal and Trinidad and others.
- those with small domestic markets, without locally exploited raw materials, unable to justify a primary fertilizer industry, and entirely dependent on imports.



Marine Terminal. Ceyhan, Turkey. (Toros Fertilizer & Chemical Ind. Co., Inc.)

In the latter category, there are over 70 countries, mainly in Africa, Central America and the Caribbean. Although they account for only 5% of the developing countries' fertilizer use, they include some of the poorest countries of the world, and some of those with the most precarious situation regarding food security.

Since the developing countries are major fertilizer importers, the international fertilizer trade suffered much less than global consumption from the situation in Europe and the former Soviet Union. Compared with the 16% fall in consumption, trade in fertilizers fell by only 4-5%, and the processed phosphate trade actually increased.⁹

Altogether, an estimated 160 - 180 million tonnes of fertilizers and their intermediates and raw materials are transported internationally every year.¹⁰ Excluding raw materials and intermediates from this figure, the finished fertilizer trade represents over 40% of world fertilizer nutrient consumption, compared with about 30% in the mid-1980s. This adds up to a

very large bill for freight. But this is only part of the picture, since the domestic cost of transporting and distributing fertilizer materials within each country is also a significant part of the cost of getting fertilizers to the farmer.

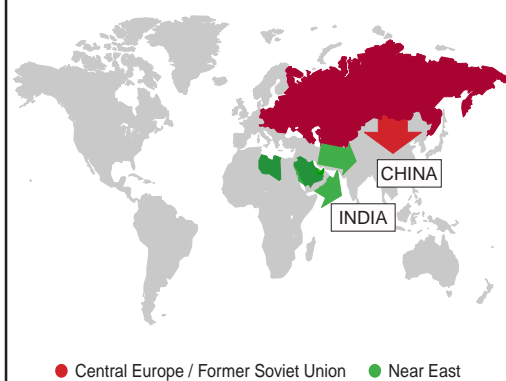
The world fertilizer trade has expanded dramatically over the past 25 years. In the decade from 1970 to 1980, exports nearly doubled from 19 to 37 million tonnes of nutrients. In the same period, the global bill for exports of manufactured fertilizers rose from US\$ 1.4 billion to US\$ 11.1 billion. By 1990, these figures had reached 49 million tonnes of nutrients, valued at US\$ 12.3 billions. Trade with and between developing countries was a motor force in this increase. In 1970, they accounted for only 35% of this trade. By 1990, they took 47%, and the figure is now well over 50%. Moreover, their processed fertilizer exports, amounting to only 6% of world trade in 1970, now account for about 17%.

Twenty years ago the main form of traded P_2O_5 was phosphate rock, which was processed into superphosphate and compound fertilizers predominantly in the developed world. During this period, however, the role of phosphate rock as an export carrier of P_2O_5 has declined sharply as vertically integrated industries have been developed at or close to the sites of rock mines. The US industry, for example, has virtually ceased to export phosphate rock, preferring to concentrate on downstream processing. The USA accounts for almost two thirds of world exports of ammonium phosphate.

In the case of nitrogen, it is necessary to distinguish between trade in ammonia and trade in nitrogen fertilizers. Most traded ammonia is used to manufacture fertilizers but considerable quantities are used to produce industrial chemicals. The trade in finished nitrogen fertilizers is primarily in the form of urea, and secondly in the form of the ammonium nitrates. Russia and some Central European countries are major suppliers of these products, having considerable surplus capacity since their domestic markets collapsed. Russia has the

Urea exports - 1997

main movements excluding intra-regional trade

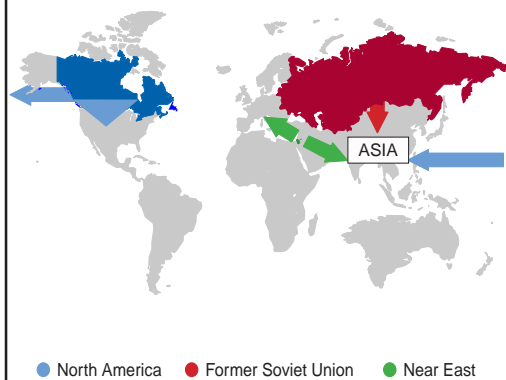


Diammonium phosphate exports 1997

main movements excluding intra-regional trade



Potash exports - 1997



6. The international market

advantage also of large reserves of natural gas. Certain countries of the Arabian Gulf and the Caribbean are also major exporters, thanks to their plentiful gas supplies.

Potash is exported from a small number of countries with a highly developed potash mining industry. Canada, Russia and Belarus, West Europe, Israel and Jordan, in that order, account for almost all the world exports. In West Europe, the main exporter is Germany, the French deposits being near exhaustion.

6.2. International prices

Generally the fertilizer industry attempts to minimize price fluctuations in domestic markets since large price variations can have lasting adverse effects. In some countries, the government controls fertilizer prices, or takes control if prices rise too far. There is no such control in the international market. This causes international price volatility of much greater dimensions than in domestic markets.

Fortunately for importers, international fertilizer prices have generally been lower than the domestic prices in the exporting countries. Nevertheless, developing countries which depend on this international market for part or all of their fertilizer supplies are particularly sensitive to the considerable fluctuations which have occurred.

Fertilizers are traded internationally at prices which are continually fluctuating, depending on availability, maritime freight rates and distance from markets. For example, between 1994 and 1998, urea was traded within a range varying from less than US\$ 100/tonne free on board (fob) to more than US\$ 220/tonne fob. When

dollar prices are then converted to the local currencies of importing countries - which have also shown major exchange fluctuations over this period - it becomes obvious that there is no such thing as a representative international price for any fertilizer for more than a very brief period.

Fluctuations in world market prices can have a disconcerting and damaging effect on the growth of fertilizer use in the important markets of the developing countries. Government budgets for fertilizer imports and subsidies can be caught off-balance. Official reactions are often too slow to prevent local supply shortages. Unless such fluctuations are cushioned at the local retail level, poor farmers, new to the experience of using fertilizers, can easily become discouraged.

Nevertheless, real situations of shortage have been historically rare in the fertilizer trade. Over-supply and severe competition has been typical of the last 20 years. In such a situation, the essential role of private exporters can easily be overlooked. Since the private sector depends entirely on its financial performance, it is quick to adjust production to balance supply and demand. Such adjustments have resulted in the closure and idling of millions of tons of fertilizer production capacity in the developed market economies.

Notes

⁹ as measured in nutrients and not including trade in raw materials and intermediates.

¹⁰ Of this, fertilizers and phosphate rock account for about 120 million metric tonnes of solid maritime trade.

7. The role of technological progress

7.1. Fertilizer technology

World fertilizer production has increased by over 60 times in the course of the 20th century. In the last 35 years alone, it has increased by 4 times to reach 136 million tonnes of nutrients. This corresponds to about 325 million tonnes of finished products. Such an expansion would have been impossible without a stream of technological progress. Consider, for example, the apparently simple idea of producing fertilizers in the form of granules. The early fertilizer products were powders. They tended to solidify when left in a damp atmosphere. They were difficult and unpleasant to handle. They could not be spread satisfactorily from machines. It would be difficult to imagine the present maritime system shipping tens of millions of tons of such materials around the world. It would be equally difficult to imagine the modern farmer accepting them.

Yet the technology of forming granules is not so simple. It has evolved considerably over the last 50 years. It is still the subject of substantial research and development. The action of “growing” granules by the agglomeration and layering of particles in the presence of a liquid

and a solid phase is the subject of many processes involving different types of equipment.

For some materials, alternatives to granulation include prilling and compacting. For example, much of the world's urea production is prilled. Prilling involves forcing molten droplets through shower-like nozzles or centrifuges at the top of high towers, so that the droplets solidify as they fall down the tower through an up-flowing stream of cold air.

With granulation, the producer may have greater control over the size of the agglomerated particles than with the prilling process. This is important for two reasons:

- the rate of release of nutrients into the soil is partly governed by the size of the granules;
- the mixing or bulk blending of different fertilizer products requires similar particle sizes - otherwise, during handling, transportation and spreading, the different products tend to become segregated again, causing unbalanced, inefficient nutrient application.

The granulation of fertilizers has permitted large savings in their packaging, handling, transport and application, and improvements in the precision of spreading them on the fields. It has made possible the transport of fertilizers in bulk to the end-user or to bagging stations in the consuming area.

Compaction of fertilizer materials into small pellets or briquettes can also be used to obtain products with improved physical properties for bulk blending or direct use.

The use of fluid fertilizers represents another technological innovation. The products vary from anhydrous ammonia to multi-nutrient suspensions.

Fertilizer granules *Prills* *Compactates*



7. The role of technological progress

A major breakthrough for the nitrogen fertilizer industry was the development of the rotating compressor. In ammonia production, large volumes of air and gas have to be pressurized. The growth of large modern ammonia plants, bringing substantial economies of scale, would not have been possible with the old reciprocating compressors.

Similarly, the development of automation, computerization and remote control technology has revolutionized production methods, especially in the fields of safety, environmental standards and quality control.

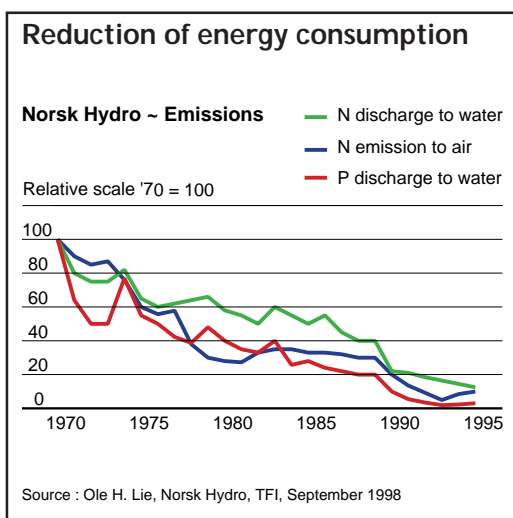
A major thrust of recent technical research in the nitrogen industry has been the effort to reduce energy consumption. An American industry survey in 1983 showed an average energy consumption of 42 MM (million) BTUs (British thermal units) per tonne of ammonia produced. By 1996, this figure was still about 38 MM BTUs, reflecting a high average age of the surveyed plants and the limits of retrofitting them with new technology. New plants built today with the best available technology can operate on about 30 MM BTUs, although additional energy consumption is required to meet rising environmental standards for emissions to air and water.



Feeding the phosphoric acid reactor with phosphate rock. Darou, Sénégal. (Industries Chimiques du Sénégal)

In phosphoric acid manufacture, the main emphasis of research has been concerned with improving the concentration of the product acid, limiting the cost of evaporation, and maximizing the yield from the raw materials. Improvements in the control of the chemical reaction have steadily raised the acid concentration, before evaporation, from 20 - 23% in the early days of the industry to 45 - 50% for the modern "hemihydrate" process. Commercial phosphoric acid is concentrated to 52 - 54%.

The quality of the phosphate rock used in phosphoric acid manufacture is a critical factor. In addition to its phosphorus content, phosphate rock contains elements which are regarded as impurities and which greatly complicate the life of the phosphoric acid production engineer. Consequently, plants are usually "tailored" for a specific source and grade of rock. Changing this source and grade is costly in terms of the time taken to re-adjust the process. A different source of rock may often necessitate additional equipment. Even the same source of rock can fluctuate in quality. In general, however, the problems associated with the diversity of phosphate rock qualities is one of the factors working in favour of the trend for new phosphoric acid plants to be situated at or near the location of a phosphate rock mine.



7.2. The future of fertilizer production

The major fertilizer products in use today are expected to continue to be the most important in the foreseeable future. No revolutionary new products are expected to take their place. More highly concentrated products are technically possible, but their commercial development is likely to be uneconomic, except in special circumstances.

The technical development of the fertilizer industry will concentrate on increasing efficiency in the production of the existing products, as well as in their agricultural use. The importance of the cost of energy will continue to drive research towards processes involving less energy, or more economic forms of it. For example, coal gasification technology has made important progress in recent years, and in some areas, local price relationships between coal and natural gas may develop to the benefit of coal as the energy source for ammonia production. However, steam reforming with natural gas will remain at the core of the ammonia industry.

The bulk of world phosphate fertilizer materials will continue to be based on the reaction of phosphate rock with sulphuric acid. The supply of sulphur has historically tended to be quite cyclical, but a substantial world surplus is expected to persist into the next century.

Potash will continue to be mainly supplied in the chloride form by conventional dry mining techniques, though special circumstances may dictate solution mining in a few locations.

Higher agronomic efficiency in the use of existing products is a principal target of research. For example, with particular soils and climatic conditions and poor or inappropriate fertilizer application, nitrogen can be volatilized into the atmosphere or leached into the subsoil. Much effort has been devoted to producing so-called "controlled-release" nitrogen fertilizers. So far the economics have generally been

unfavourable. Consequently, their use has been limited to high value crops, horticulture, and recreational facilities, and they account for less than 0.2% of the global mineral fertilizer market.

Similarly, extensive research is being devoted to the development of suitable economic methods and equipment for applying fertilizers so that nitrogen losses are minimized. Nitrification and urease inhibitors have been shown to reduce the nitrogen fertilizer requirement for a given crop yield by up to 20%, but their use is not yet widespread and may depend on the future restriction of nitrogen use for environmental reasons.

Large modern fertilizer complexes require sophisticated management and a fundamental understanding of the unit processes involved. Process efficiency is a function of the operational stability of the plant. With increasing capital intensity, the cost of downtime becomes critically important. Most new investment will continue to be in Africa, Asia and Latin America where the capital investment per tonne of product is often higher than in Europe and North America. It is therefore all the more important for these regions to develop an adequate body of highly knowledgeable, experienced engineers and skilled labour.

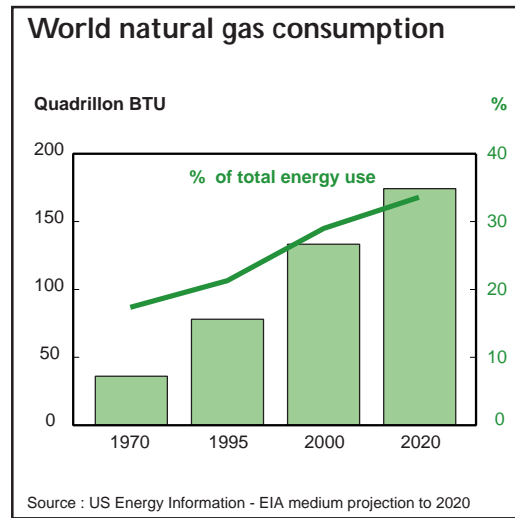
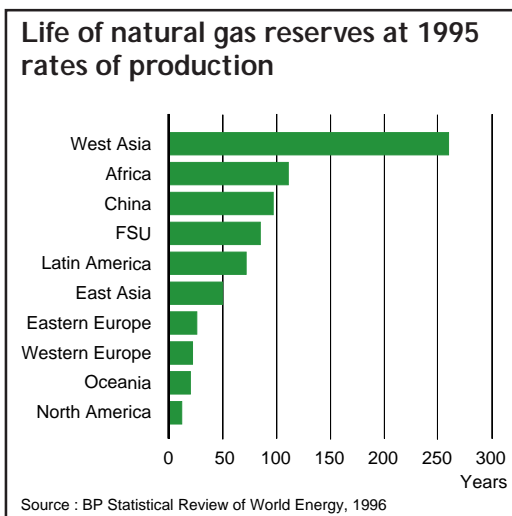
Certain developing countries are successfully investing in their own fertilizer production research and development, and their own engineering capabilities. Nevertheless, for the time being, they continue to depend heavily on the strength of research and engineering in the developed market economies. Though generally constrained by low capital returns over many years, continuing investment in the development of technology holds the promise of further improvement in the key parameters affecting the economics of fertilizer production, particularly in the fields of energy and raw materials efficiency, capital cost reliability, environmental control and ease of plant operation.

8. Will there be enough raw materials?

The main fertilizer raw materials - as indicated earlier - are energy, phosphate rock, sulphur and potassium salts. In the continuing debate on sustainability, the possible exhaustion of essential minerals is of central concern. Are we in danger of exhausting the supply of raw materials for the fertilizer industry or of compromising the ability of future generations to meet their own needs?

8.1. Energy

The high-temperature catalytic synthesis of ammonia from air and a source of hydrocarbons is by far the main consumer of energy in the fertilizer industry. Natural gas is the preferred feedstock. The diagram below shows one estimate of the size of regional gas reserves in 1995 in terms of years of production at 1995 production rates. Such estimates are subject to many qualifications, particularly international differences in reporting criteria; but in the picture presented below, total world gas reserves in 1995 amounted to 66 years of production.



This compares with 55 years in 1983, reflecting the discovery of new deposits in the intervening years, as well as upward revision of the size of existing deposits.

Processes for ammonia production can use a wide range of energy sources. Thus, even when oil and gas supplies eventually dwindle, very large reserves of coal are likely to remain, albeit with costly problems of pollution control overhanging their use. Many scientists expect that, before the exhaustion of such mineral sources of energy, the development of economic energy from a variety of renewable natural sources will provide a safe, permanent solution to this problem. However, the use of natural gas is accelerating rapidly, mainly because of environmental pressures which work against other fossil fuels. The diagram above shows that natural gas is expected to account for about one third of global energy use in 2020, compared with only one fifth in the mid-1990s.

The entire fertilizer industry uses less than 2% of world energy consumption, and this is overwhelmingly concentrated in the production

of ammonia. The ammonia industry used about 5% of natural gas consumption in the mid-1990s - a figure which is expected to diminish substantially in coming years. Consequently, it has little or no influence on world energy prices, and only rarely on local energy prices.

8.2. Phosphate rock

Mineral phosphates are composed chiefly of one or more complex fluorine-containing calcium phosphates. They are insoluble in water but readily soluble in dilute acids. They originate either from volcanic action along zones of weakness in the earth's crust, or from sedimentary deposits on the ocean bed, usually in shallow coastal areas which subsequently became land. Sedimentary deposits account for the bulk of commercial phosphate production.



Geological evolution is too slow to replenish the amounts being mined, and commercial mining always extracts the richer ore first. The world average P_2O_5 content of phosphate rock in 1975 was about 32.5%, whilst today it has fallen to 31%. We can expect a continuing, gradual diminution in the average quality of the mined ore. This is compensated by more efficient technology for enriching the ore to meet commercial processing standards. At the

Mineral Reserves and Resources

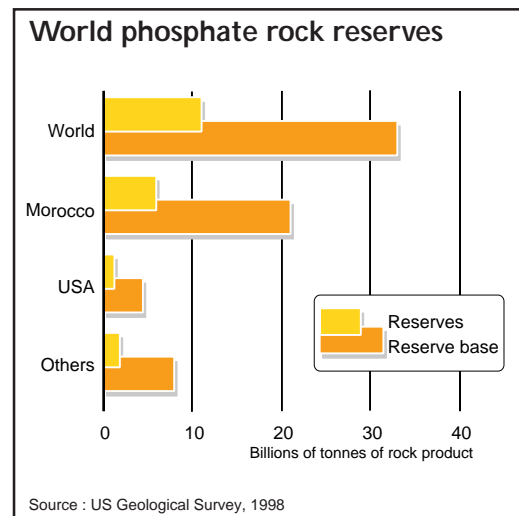
A **reserve** is usually defined as a mineral deposit of established extension that is - or could be - profitably mined under prevailing costs, market prices and technology.

A **resource** is considered to be a deposit of less well defined size which is not now economically exploitable but which could potentially become so, if there was a sufficiently favourable change in costs, prices or technology.

same time, processing technology is finding economic ways of using lower-grade ores.

In the case of a mineral with such a diversity of grades, compositions and locations as phosphate rock, the quantitative evaluation of reserves and resources is necessarily subjective and variable over time. Firstly, geologists are not unanimous on what methods and definitions to use for this evaluation. Secondly, many deposits are only partially explored, and new discoveries change the picture. Thirdly, the size of reserves depends on prevailing costs and prices.

In 1998, the US Geological Survey estimated that world phosphate rock reserves amounted to about 11 billion tonnes, with a larger reserve base of about 33 billion tonnes. The heavy concentration of these reserves in just one country - Morocco - is illustrated in the diagram below.



At the present rate of mining, world phosphate reserves would last for about 80 years and the reserve base for about 240 years. However, the respective figures for Morocco are 280 and 1000 years, and the figures for the rest of the world are only 45 and 100 years. Consequently, in the longer term, there will be an increasing reliance on Morocco, which currently accounts for only 15% of world production. It is not difficult to imagine that, in due course, the expansion of production in

8. Will there be enough raw materials?

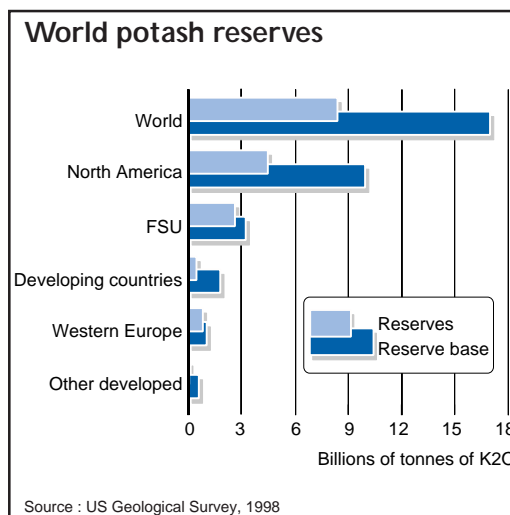
Morocco which would be required to offset diminishing deposits in other countries and meet a growing world demand, would inevitably create serious logistic and environmental problems, not to mention an eventual monopoly, unless major new sources emerge in the meantime.

On the other hand, as the need arises, a doubling or trebling of the present real price of phosphate would produce a very large increase in the economic reserves of numerous countries and open the possibility of mining the large phosphate resources identified on the continental shelves and on seamounts in the Atlantic and Pacific Oceans. Perhaps within the next century the problem of virtually limitless low cost renewable energy may be solved. In this case, with changing technology, it may become possible to exploit the very large identified resources which presently fall outside the reserve base¹¹ - or even to "mine" sea water for its phosphorus and other minerals.

8.3. Potash

Potassium salts occur as underground deposits or in salt lakes. Commercially economic sources are less widely distributed than in the case of phosphate. In fact, both economic reserves and resources are heavily concentrated in two regions - North America and the former Soviet Union. As shown in the diagram on the right, these regions presently have 85% of known economic reserves, and a similar share of the reserve base.

Although potash, like phosphate, is a non-renewable resource, the known reserves and resources are much larger than for phosphate. At mid-1990s rates of production, world potash reserves would last for 320 years, and the reserve base offers 650 years. At 250 billion tonnes of K_2O , potential world potash resources are truly vast.¹²



Nevertheless, over the next 50 years, some potash producers will be obliged to mine lower grade ores, deeper layers or more distant regions. New potash deposits are still being found and new producers may appear; the world food situation should not be endangered by a lack of potash. But, as for phosphate, one country - Canada - has well over 50% of world reserves and of the reserve base and would, in due course, be in a commanding position, without the discovery of further major deposits.

Potash mining. (*Kali & Salz*)



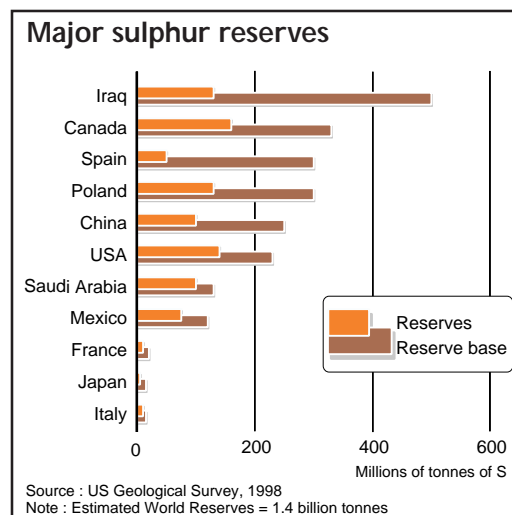
8.4. Sulphur

Sulphur is found in volcanic rocks, in association with salt domes, in metal ores and as sulphides associated with oil and coal. Sulphur resources are very large, but only a small fraction is economically exploitable. Gypsum and anhydrite constitute a large part of resources, and they are not economically exploitable for their sulphur content under present circumstances.

Nevertheless, the presently exploitable fraction of sulphur resources is also very large - 1.4 billion tonnes of elemental sulphur (S), with a reserve base estimated at 3.5 billion tonnes.

According to the US Geological Survey, "resources of elemental sulphur in evaporite and volcanic deposits and sulphur associated with natural gas, petroleum, tar sands and metal sulphides amount to about 5 billion tonnes. The sulphur in gypsum and anhydrite is almost limitless and some 600 billion tonnes are contained in coal, oil shale and shale rich in organic matter, but low-cost methods have not been developed to recover sulphur from these sources."

About two thirds of world sulphur supplies are produced as elemental sulphur, and of this about 85% is recovered from hydrocarbon sources. This part of production fluctuates with world energy demand, and the availability of sulphur in other forms is affected by trends in other industries. The ability of the sulphur



mining industry to hold the balance of demand depends on the price outlook, which is largely governed by the prospects for phosphate fertilizer demand.

Notes

¹¹E.g. R.P. Sheldon estimates 112 billion tonnes as the actual and inferred reserve base: *Industrial Minerals with emphasis on Phosphate Rock in Resources and World Development*, ed. McLaren & Skinner, pub. J. Wiley & Son, New York, 1987.

¹²Resource estimates differ very widely. One estimate puts the potash resources of Saskatchewan alone at over 500 billion tonnes K_2O . See Mayrhofer H, 1983, *World Reserves of Minable Potash Salts*, The Salt Institute, Alexandria, VA, USA.

Sulphur storage. Lacq, France. (L. Isy-Schwartz, Elf Atochem)



9. Will there be enough fertilizers?

Analysis of regional supply and demand balances reveals some interesting trends. For example, the world nitrogen balance has become heavily dependent on the FSU and Central Europe. In the late 1970s and early 1980s, rising energy costs in the industrialized market economies, lack of demand and low - or even negative - capital returns combined to cause the shut down of millions of tons of ammonia and nitrogen fertilizer capacity in America, Western Europe and Japan. After 1989, the dramatic fall in domestic demand in the FSU and Central Europe sharply increased an already large excess of potential supply over demand in these regions. Now, in the late 1990s, economic factors favour the Middle East, where production capacity is expected to increase rapidly in the next few years.

Since it takes two or three years to construct and bring a new fertilizer plant into operation, and in view of the large investment involved, it is necessary to assess the future supply/demand balances of the major nutrients. Concerned about the shortage of mineral fertilizers at the time of the 1974 oil crisis, and the importance of fertilizers in world food supplies, the 1974 World Food Conference established a working group of relevant members of the UN family of organizations, the Food and Agriculture Organization (FAO), the World Bank and the United Nations Industrial Development Organization (UNIDO), to assess the supply/demand balances some five years ahead, for nitrogen, phosphate and potash. The fertilizer industry has co-operated closely with this group, which has continued to produce its supply/demand balances each year ever since. Because

a new fertilizer plant can be constructed and come into operation within a period of about three years, it is not possible to forecast the supply/demand balance more than five years ahead.

The supply/demand balance is calculated by comparing forecast demand with estimates of production capacities of nitrogen, phosphate and potash fertilizers. The supply is "potential" in that, if the demand does not materialize, there will be surplus capacity available on the world market. Since 1974, on no occasion has the Group's supply/demand assessments shown anything other than a surplus in each of the three major nutrients.

At times the surplus has been large and international prices have fallen to very low levels. The same is true today. Supplies of ammonia and of nitrogen and potash fertilizers will be more than adequate during the foreseeable future. The situation for phosphates is somewhat closer to balance; the poor results of the 1980s and early 1990s discouraged new investments and both private and public sector investors are now much more cautious than they were in the 1970s. It takes longer to establish a new phosphate rock mine than it does to build a new fertilizer plant, especially in regions where the delivery of permits is strictly controlled and the investment is particularly high; if there is to be a tight situation in the coming years it could be in the availability of phosphate rock, especially rock of good quality. Of course, there are many uncertainties, amongst which is the export capability of Russia and fertilizer demand in China.

10. How can the effect of fertilizers be improved?

10.1. The need for good management

The use of fertilizer requires “know-how”. If applied at the wrong time or in the wrong dosage or without other necessary crop management techniques, its effect is greatly diminished and may easily be unprofitable. The amount of increase in the harvest which is derived from fertilizer use depends on many other factors. Among these are:

- the adequacy of soil moisture during crop growth;
- the adequacy of different nutrient availabilities in the soil;
- the yield potential and fertilizer responsiveness of the crop variety;
- the extent of pest infestation and corresponding crop protection measures;
- methods of soil and soil fertility management.

Uneven nutrient distribution causes "stripe" and lower yields. Germany. (BASF AG)



Some factors, particularly those related to climate, are beyond the control of the farmer and represent risks which affect his willingness to buy fertilizers.

Interaction between different crop production factors, including fertilizers, can produce surprising synergistic effects. Cooke¹³ has stated that “in a highly developed agriculture, large increases in yield potential will mostly come from interaction effects. Farmers must be ready to test all new advances that may raise yield potentials of their crops and be prepared to try combinations of two or more practices.”

In developing countries, farmers may be reluctant to experiment. This reflects the relatively larger financial risk which they often have to face, as well as lack of knowledge and experience of fertilizer use. Where government policies can minimize such risks, farmers in these countries prove to be just as flexible as their counterparts in developed countries, and then the search for effective combinations of good practices can yield spectacular results. Among the factors affecting fertilizer efficiency are:

- selection of appropriate crops and crop varieties;
- depth and time of tillage and sowing;
- seed density and plant spacing;
- existing soil conditions, especially organic matter content;
- choice of fertilizer and combination of nutrients;
- rate, method and timing of fertilizer application;
- control of weeds and pests;
- irrigation and water management;
- harvesting efficiency.

10. How can the effect of fertilizers be improved?

The crop response to increasing amounts of fertilizer is a function of the combination of all inputs and management practices, and their judicious selection and use depends on the farmer's knowledge and ability, supplemented by the advice obtainable from agricultural extension services. The latter depend absolutely on the quality of agricultural research services.

10.2. Improving fertilizer efficiency

Fertilizer research and development has historically been mainly concerned with maximizing the economic yield increase from a given rate of nutrient application. More recently, much research has been concerned with minimizing potentially adverse environmental effects of fertilizer use. In general, the two objectives are entirely compatible: inefficient fertilizer use has adverse effects on both. Any one of the factors mentioned above can severely reduce fertilizer efficiency, though experience has shown the most important to be unbalanced fertilizer use, inappropriate crop varieties and delay in sowing.

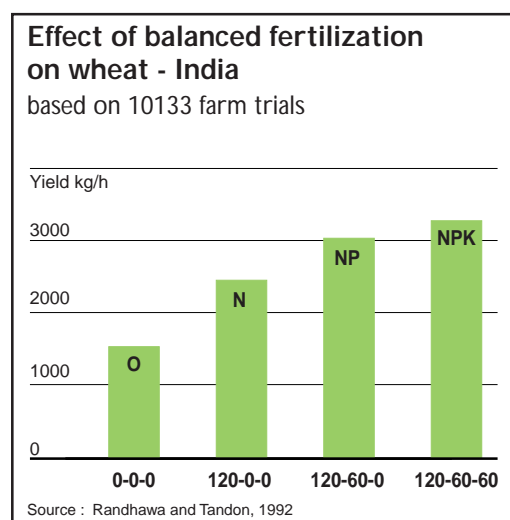
Each of the major nutrients has its own characteristics affecting the efficiency of its use in fertilizers. Nitrogen, for example, is highly mobile in the soil and is easily lost through leaching, denitrification and volatilization. The timing and method of application of nitrogen fertilizers is crucial. With phosphate and potash, there are important residual effects from previous applications to be considered, since only a part of these nutrients is taken up by the crop for which they are applied. Soluble phosphate is rapidly transformed in the soil into less soluble forms, which are then re-solubilized only very slowly.

In tropical and sub-tropical regions, soil acidity is a severe constraint to plant growth and yield improvement. For example, 50% of the total arable area of tropical Latin America is affected in this way. This can be corrected by the application of limestone, but in many

developing countries agricultural lime is not available at an economic cost.

10.3. The importance of balanced plant nutrition

In the initial stages of fertilizer use, farmers tend to use only nitrogen, if it is available. Farmers in Europe and America were immensely favoured by the fact that phosphate and potash fertilizers became generally available many years before an economic process for the large-scale manufacture of nitrogen fertilizers was discovered. This allowed a gradual improvement in the phosphorus and potash status of soils in these regions. Farmers in developing countries do not enjoy this advantage. On land where organic manuring has been well practiced, this is not initially serious; and even on land which has received little or no previous manuring, nitrogen usually gives spectacular results. But with a succession of larger crops, the soil contents of phosphate and potash, as well as of other macro- and micro-nutrients, become depleted; and this, in turn, leads to a decline in the efficiency of nitrogen use. Sometimes this can happen quite rapidly. In severe cases, an increase in nitrogen use, without supplying other nutrients, can actually decrease yields.



The proportions of nitrogen, phosphate and potash in total fertilizer use vary greatly between countries and regions. Different crops and soils need different amounts of each nutrient. Countries are, in any case, at different stages of agricultural development, and the balance between the nutrients used in agriculture is influenced by the available knowledge among farmers. Developing countries where subsistence food crops predominate will usually use more nitrogen than other nutrients. Countries with large areas of cash crops usually have a more balanced ratio between the nutrients.

10.4. Fertilizer response ratios

Fertilizer response ratios can be useful indicators for estimating how much increased crop production might be expected from a certain

level of fertilizer use. These ratios represent the amount of output per unit of nutrient input. They can be general estimates or specific values for given locations and conditions.

Numerous experts have calculated average response ratios for cereals, primarily wheat and rice, in developing countries. As might be expected, their figures vary substantially, depending on all the factors mentioned above. As a general guide, it is often assumed that one unit of balanced nutrient supply ($N + P_2O_5 + K_2O$), when efficiently used, should produce about 10 units of grain. But this masks large variations and takes no account of the cumulative residual effects of building up the basic level of soil fertility through repeated application of fertilizers over several years. Unbalanced fertilizer use results in diminishing response ratios, especially where irrigation is mismanaged and deficiencies are only partly corrected by organic manures.

11. Economics of fertilizer use

As regular fertilizer use becomes established, the farmer who manages the land with care will gradually improve its basic fertility. The residual effect of fertilizer use will increase the value of the land, as well as its profitability. However, the farmer's main immediate concern is the amount and probable value of the additional crop which will be obtained from the next use of a certain amount of fertilizer. Consideration will also be given to whether it should be bought for cash or on credit, whether there are more profitable uses for the capital - and the risks involved.

Three basic concepts are used to assess the profitability of fertilizer use: the net return (or profit), the value/cost ratio (VCR), and the crop price/fertilizer cost ratio.

11.1. Net return

The net profit from fertilizer use is probably the most significant indicator for the farmer. In theory, net returns reach a maximum when the cash value of the additional crop obtained from the last additional unit of applied fertilizer is equal to the cost of that fertilizer unit.

This is often calculated from yield experiments, but it obviously varies from year to year, depending on changing prices, weather conditions and other uncertainties. This is why farmers in developing countries, where the risks are high, generally apply fertilizer at a rate much lower than the one necessary to obtain the maximum net return. They cannot afford to overshoot this moving target and, in any case, they often lack the finance to use recommended fertilizer amounts.

Nevertheless, it is true that the nearer a farmer can get to the maximum net return, the lower his cost per unit of crop becomes, even

though his expenses on inputs increases. This is because there are certain fixed costs which must be covered irrespective of the crop yield. Consequently, as yields grow, these fixed costs can be spread over more units of crop production.

11.2. Value/cost ratio (VCR)

The value/cost ratio, or VCR, is very widely used to indicate the profitability of fertilizer use. It represents the value of the increase in the crop, divided by the cost of the fertilizer which produced this increase. If the VCR is greater than one, the fertilizer has been profitable.

For reasons indicated above, farmers in developing countries will generally not use fertilizer unless they expect a VCR of at least two.

Unfortunately, this indicator can be misleading. Firstly, it disregards the "added value" of previous fertilizer applications - the cumulative improvement of the natural fertility of the soil. Secondly, the highest VCR usually occurs at the lower end of the yield response curve. A high VCR often coincides with relatively high total production costs per unit of crop production. In extreme cases, a high VCR can be associated with a negative net return, if total crop production costs are considered. The VCR should always be considered together with the net return.

The FAO Fertilizer Programme was undoubtedly the most universal proof of the high potential returns to fertilizer use. Beginning in 1961, it operated for more than thirty years, passing through 40 countries with about one quarter of a million simple trials and demonstrations in ordinary farmers' fields. The average VCR was nearly 5, and the best

fertilizer treatment increased crop yields by 50 to 100% depending on the region.

The greatest agricultural challenge in the tropics and subtropics is often considered to be the gap between research results and the actual achievements of farmers. In the Philippines, the FAO Fertilizer Programme showed that 55% of the difference between experimental rice yields and farmers' yields was due to differences in fertilizer use, whilst another 40% was due to insect and weed control.

11.3. Fertilizer/crop price ratio

Before a farmer decides to use fertilizer, he will always try to assess the likely selling price for his crops and relate this to the cost of the fertilizer and its likely effect. Higher fertilizer prices or, alternatively, an expectation of lower crop prices can induce lower use of fertilizer. However, the farmer can often be wrong, since he may not appreciate that the effect on his profits of a change in fertilizer prices is probably not nearly so great as the same percentage change in his crop price.

In the Philippines, for example, data from 541 trials on rice showed that an increase of 40% in the price of nitrogen depressed the net

return by only 18% with a constant paddy rice price; but a similar fall in the crop would have reduced the net return by 58% with a constant nitrogen price. This indicates the great importance of government policies which affect the ratio between fertilizer prices and crop prices.

No single economic indicator can determine how much fertilizer a farmer can profitably use in a given case. Different input/output price relationships, various social and political constraints, the availability of necessary resources, the ability and willingness to take risks - all these factors affect the optimum level of fertilizer use and the farmer's decisions. In general, farmers throughout Africa, Asia and Latin America apply substantially less than either the recommended balanced dose or the amount which would give them most profit. This represents a large, untapped potential for improving farm incomes, national food production and the welfare of vast populations.

In general, in developing countries, the low profitability of fertilizer use relates foremost to crop prices. Changes in demand for fertilizer tend to be three times more sensitive to changes in output price than to fertilizer cost.

The N-tester chlorophyll meter can measure N-status in the crop so that final application of nitrogen can be fine tuned to meet the crop's precise needs. (Norsk Hydro A.S.)



Notes

¹³G. Cooke, *Fertilizing for maximum yield*, pub. Crosby Lockwood, London, 1972.

12. Fertilizer production and the environment

As with all chemical process industries, the production of mineral fertilizers gives rise to emissions, which contribute to environmental problems, both globally and locally. Over the last 25 years, much research and expenditure has been devoted to minimizing these emissions. Like other industries, the fertilizer industry started with factories which would be totally unacceptable today, both in terms of their waste emissions and their internal working environment. In the industrialized countries, the emergence of environmental conservation as a major political issue led to tight regulation of manufacturing industries, not least the fertilizer industry. Many developing countries - especially those with high population densities - are also adopting stricter environmental controls, despite the immediate economic cost which this entails.

The environmental impact of a fertilizer plant depends on a wide variety of circumstances, including the nature of the plant, the processes and raw materials or feedstocks which it uses, the location of the site, the nature of its surroundings, the regulations to which it must conform and the expertise of its management. For various reasons, many plants do not yet practise the best available technologies (BATs) which international organizations such as the European Fertilizer Manufacturers Association (EFMA) are promoting. Consequently, it is impossible to generalize about the environmental impact of fertilizer production, but the main problems are as follows.

12.1. Ammonia and nitrogen fertilizer production

The production of ammonia generates substantial amounts of carbon dioxide (CO₂), which contributes to global warming. If natural gas is used as the feedstock in a modern steam-reforming plant, about 2.7 tonnes of CO₂ per tonne of nitrogen are produced. If coal or fuel oil are used, this figure is about 25% higher. On the other hand, the production of urea requires an *input* of about 1.6 tonnes of CO₂ per tonne of nitrogen.

The fertilizer industry's share of the annual net addition of CO₂ to the atmosphere resulting from human activities is estimated at 2%; and human activities account for only 7% of the quantity released annually by biological processes. Consequently, the share of fertilizer production in the total annual release of CO₂ to the atmosphere is very small - in the range of 0.1-0.2%. Nevertheless, the projected growth of fertilizer use makes it all the more desirable that the industry should keep CO₂ emissions as low as possible. Since technological limits to energy efficiency have been almost attained, future limitation of CO₂ emissions will have to come from the replacement of old, inefficient plants.

The production of nitric acid, used for ammonium nitrate and nitrophosphate fertilizers, gives rise to the emission of nitrous oxide (N₂O), which is a much more potent global warming agent than carbon dioxide. It is also considered to be detrimental to the ozone layer. The rate of emission varies widely from 1 to more than 10 kg N₂O per tonne of 100% nitric acid. Abatement techniques can greatly reduce such emissions but are costly. It is estimated that fertilizer production currently accounts for about 6% of man-made N₂O emissions, compared with



Ammonia being unloaded from ship to storage tank at Visakhapatnam storage terminal. India. (Godavari Fertilizers)

nearly 50% from motor vehicles. Most N_2O recycles to land and water, and, as with CO_2 , vastly larger quantities are emitted through natural biological processes. N_2O is estimated to be responsible for 7.5% of the calculated global warming effect of human activities.

Consequently, fertilizer production is responsible for less than 0.5% of this effect (0.06×0.075).

An advantage of the nitrophosphate process is that it does not involve the production of sulphuric acid and phosphoric acid and thus avoids the disposal of the huge amounts of phosphogypsum which result from the phosphoric acid process. Calcium ammonium nitrate is a co-product of the nitrophosphate process.

Nitrogen oxides (NO_x) are also emitted from ammonia and nitric acid plants. Nitric oxide is oxidized over a few days to nitrogen dioxide, which has an atmospheric residence time of about a week and is deposited in air, rain, or as nitrate particulates. This contributes to acid rain and smog. In the case of ammonia, emissions are only about 1-2 kg NO_x per tonne of nitrogen. With nitric acid, NO_x emissions amount to 6-9 kg N per tonne of converted nitrogen. Selective catalytic reduction, using ammonia to convert NO_x to nitrogen, is an effective means of abatement, and more than half a million tonnes of ammonia are now used annually for this purpose.

The storage, handling and transportation of ammonia and ammonium nitrate, as well as compounds containing ammonium nitrate, have been the subject of much research, regulation and public advice. These products, together with the commonly used acids, present various hazards if the relevant regulations are ignored or disrespected.

12.2. Phosphate fertilizer production

Acid rain is also produced by the emission of sulphur compounds. As far as the fertilizer industry is concerned, these result mainly from the production of sulphuric acid and phosphate fertilizers, but ammonia production can also be responsible where coal and fuel oil are used as feedstocks. Most of the gaseous sulphur compounds emitted in the course of fertilizer production can be recovered by scrubbing and filtration, but much depends on the age and efficiency of the plant. Regulations concerning maximum concentrations discharged to the atmosphere and minimum sulphur conversion efficiencies are universal.

Mineral phosphate normally contains 3-4.5% of fluorine. Its acidulation releases fluoride compounds which are scrubbed to reduce atmospheric emissions to required levels. The resulting fluosilicic acid has potential commercial value, but, if unsold, it can be neutralized by liming. Part of the fluorine remains in the fertilizer and, in the case of phosphoric acid production, part remains in the waste phosphogypsum resulting from the reaction process.

About 4-5 tonnes of phosphogypsum are produced for each tonne of P_2O_5 converted into phosphoric acid. This impure gypsum is mainly calcium sulphate, but, apart from fluorine, it also contains trace amounts of various elements, transferred from the phosphate rock. These can include arsenic, nickel, cadmium, lead, radium and aluminium. The radium decomposes to radon gas. Consequently, the disposal of

12. Fertilizer production and the environment



Bagging of phosphogypsum for use as a soil amendment. Darou-Khoudoss, Sénégal. (Industries Chimiques du Sénégal)

phosphogypsum is a considerable environmental problem with serious implications for phosphate fertilizer production, most of which add to the cost of the fertilizer.

The nature and amount of impurities in phosphate rock depends on its origin. Different sources of rock vary widely in composition. For example, the cadmium content of phosphate rock varies from almost zero to over 300 mg/kg P_2O_5 .

Above certain limits, cadmium becomes toxic in living organisms. It is naturally present in all soils in widely varying amounts, and different crops take up cadmium at different rates. Part of the cadmium taken up by animal organisms accumulates in their bodies and part is excreted. Thus, apart from phosphate fertilizers, animal manure and sewage sludge also contribute cadmium to soils. Atmospheric deposits resulting from industrial activities are also significant. Where the contribution from phosphate fertilizers is a sufficient concern, the only alternatives are to control the source of phosphate and the amount applied to the land, or to use cadmium separation processes. Limiting phosphate processing to low-cadmium sources of phosphate rock prejudices the use of phosphates from a wide variety of countries, mostly in the developing world, with harmful consequences for their economies. Separating

cadmium from the rock is currently too expensive for fertilizers, and is presently confined to phosphates for human and animal consumption. Processes for separating cadmium from phosphoric acid show promise, but are expensive and not yet widely applied. Even if they were, this would not affect the large volume of phosphate fertilizers - mainly single superphosphate - which are manufactured without a phosphoric acid stage.

12.3. Waste disposal

The disposal of waste phosphogypsum has been previously mentioned. It is but one example of solid and liquid waste materials generated by fertilizer production. In the case of ammonia production, catalysts have to be replaced every few years. Spent catalysts can contain oxides of a variety of metals, as well as other chemicals, but most of them can be recycled or used for other purposes. Where sulphuric acid uses sources of sulphur other than brimstone, the resulting cinders can sometimes be used for

Wetlands/scrub area reclamation after phosphate mining. USA. (IMC Global, Inc.)



their metal content. Other wastes requiring specialized disposal include wastewater treatment sludges, scrubber wastes and filter dust, filter bags and empty chemical containers.

As more and more old fertilizer plants are shut down for economic or environmental reasons, and phosphate and potash mines are exhausted, the problems of site remediation and clean-up are assuming growing importance. Since the owner is liable for harm to third parties resulting from site contamination, he is normally involved in a complex and costly process of plant decommissioning and site remediation. However, standards differ widely from country to country, regulations are sometimes ambiguous, and their enforcement is not always adequate.

In brief, fertilizer production requires the most advanced environmental management systems if it is to minimize its potential for creating environmental damage. Such systems, involving use of the best available technologies and expert management, relate not only to the chemical processes involved but also to the storage, transportation and handling of the downstream production and waste materials. Where proper systems are adopted, the contribution of fertilizer production to environmental pollution can be maintained within acceptable limits. Fertilizer manufacturers are generally aware of their responsibilities in this field, and governments are increasingly involved, both nationally and internationally, in ensuring correct standards of operation.

13. Environmental aspects of fertilizer use

The use of fertilizers to increase crop yields has been the target of much biased criticism in recent years - biased because the media of the developed world have chosen to concentrate almost exclusively on adverse aspects, to the virtual exclusion of positive aspects, which could, after all, be easily presented as the adverse effects of not using fertilizers.

All human activities affect the natural environment in some way; and what is adverse or beneficial usually depends partly on one's point of view. The long-term sustainability of any system requires complicated trade-offs between benefits and losses. Almost always, there are ways of minimizing losses whilst retaining benefits. The use of fertilizers is no exception, but farmers must have the necessary knowledge. They must know how to use fertilizers efficiently in particular circumstances. Farmers must therefore learn a certain minimum of a complicated science or have access to, and make use of, adequate advisory services. Most of the adverse effects of fertilizer use result from inadequate knowledge among farmers. Bridging this knowledge gap is a more positive approach to environmental protection than condemning its effects. In this respect, the FAO Fertilizer Programme was exemplary.

The following are some of the hazards commonly associated with fertilizers :

- they destroy soil fertility - the more they are used, the more they have to be used to achieve the same crop yield;
- they diminish food quality - the use of organic manure is healthier;
- they pollute soil with toxic heavy metals such as cadmium;
- they pollute ground waters by leaching nitrates, which can adversely affect the

quality of drinking water and increase specific health hazards;

- they pollute lakes, rivers and coastal waters by erosion and run-off, which can lead to eutrophication (algal blooms), adversely affecting fish and other aquatic life;
- they pollute the atmosphere through increased denitrification and ammonia volatilization, and they contribute to global warming.

13.1. Soil fertility

Soil fertility is a concept with numerous definitions. At its simplest and most subjective, it is the latent capacity of the soil to supply nutrients to plants - a quality which must be sustained to ensure future food supplies, an unquantifiable promise of future fruitfulness.

At another, more scientific level, it may be regarded as a combination of soil properties which, *in the future*, with a given set of external inputs such as climate, cultivation, irrigation, and

Smallholder farm couple incorporating crop residues in the soil to improve soil fertility. This work must be done soon after harvest to enable timely decomposition. Malawi. (FAO)



so forth, may be expected to produce a certain amount of a given crop. For a given soil, fertility varies over time and by crop or cropping system and is affected by the combined effect of all the external inputs. The combination of soil properties which constitutes soil fertility comprises not only the amounts and forms of the different plant nutrients, but also other chemical characteristics such as acidity or alkalinity, physical features such as bulk density, water-holding capacity, rooting depth, and biological properties involving the vast array of subterranean life without which the soil would rapidly become sterile.

Soil fertility should not be confused with soil productivity. The latter is a quantitative concept and relates to the past and the present - how much has been or is being produced.

As a result of agricultural surpluses in developed countries, concern for soil productivity, which formerly took political precedence and which obviously must still prevail in the developing countries, has become overshadowed by concern for the sustainability of soil fertility. Intensive, high-input agriculture is suspected of undermining long-term soil fertility. It is argued that the resulting high outputs may deplete the soil of elements and properties which are not included in the inputs. In particular, the complexity of the skills and knowledge required to manage high-input agriculture efficiently may be too great, causing a progressive degradation of the balance of the physical, biological and chemical characteristics which constitute soil fertility - a balance which the simpler traditional low-input organic agriculture could more easily preserve. The use of agro-chemicals - fertilizers and pesticides - tends to be perceived as a proxy for this complexity. Though totally different in their purpose, chemical composition and potential hazards, fertilizers are sometimes grouped together with synthesized chemicals.

What is the evidence that fertilizers degrade soil fertility? The overuse or misuse of fertilizers

can, of course, produce effects which seem to support this thesis. Sometimes fertilizers are blamed for effects which have little or nothing to do with them. For example, problems of salinity are sometimes blamed on fertilizers, where the predominant causes are poor drainage and excessive irrigation. Moreover, declining crop responses to fertilizers are inevitable if the application of nutrients is repeatedly unbalanced and does not correspond to the needs of the soil and the crops grown upon it. Similarly, neglect of the need for adequate macro-nutrients (calcium, magnesium, sulphur) and micro-nutrients also leads to declining responses to the major nutrients. Blaming such effects on fertilizers *per se* is like blaming human obesity or malnutrition on food.

The only true way of assessing the effect of fertilizers on soil fertility is to conduct long-term experiments, using fertilizers correctly in conjunction with the best available agricultural practices. No such experiments have ever shown that the use of fertilizers results in declining soil fertility. On the contrary, the oldest continuous fertilizer experiment in the world at Rothamsted in the U.K. shows that, where mineral fertilizers have been continuously used for *more than 150 years*, the soil is more productive now than at any time in the past. Similarly, at Askov in Denmark, mineral fertilizers have consistently

For centuries, recycling of organic matter has played an important role in rice-based agriculture. Yield increases can be achieved through application at 8-10 tonnes of farmyard manure per ha. Northern Vietnam. (Potash & Phosphate Institute, East & Southeast Asia Programs)



13. Environmental aspects of fertilizer use

proved more effective than the same amount of nutrients from *organic* sources over *more than half a century*. Well-fertilized crops produce larger root systems and greater amounts of residues which decay to enhance soil structure, organic matter content and water retention capacity, thus improving soil fertility.

In the world as a whole, but especially in the developing countries, year after year, far more nutrients are being extracted from soils than are being replaced. This calculation can be made by subtracting outputs (crop nutrient contents and natural losses) from inputs (nutrient inputs from fertilizers, manures, legumes, crop residues and natural deposits). This involves complicated, debateable estimates, but, allowing for wide margins of error, the FAO has described plant nutrient depletion in many developing countries as “a real and immediate threat to food security and to the lives and livelihoods of millions of people.”¹⁴

A recent report on the world food situation says that “past and current failures to replenish soil nutrients in many countries must be rectified through the balanced and efficient use of organic and inorganic plant nutrients and through improved soil management practices. While some of the plant nutrient requirements can be met through the application of organic materials available on the farm or in the community, such materials are insufficient to replenish the plant nutrients removed from the soils. It is critical that fertilizer use be expanded in those countries where a large share of the population is food insecure.”¹⁵

In contrast to this, some campaigners argue that farmers should be able to operate within a virtually closed nutrient cycle. They claim that it should be possible for nutrients extracted from the soil to be passed through the food chain and recycled back to the soil. Organic farmers pursue this course, albeit with reduced yields, which are compensated by substantial premiums on the price of their products. By means of these premiums, they achieve economic yields, but

only because, accounting, as they do, for a only a small share of agricultural production, they can rely on sufficient supplies of organic nutrients, either by importing manure and/or animal feeding stuffs from off their farms or by allocating sufficient land to animals and/or nitrogen-fixing legumes. In the former case, they are importing nutrients. In the latter case, much of their land is effectively devoted to supplying nutrients to the remainder, and their marketed produce still drains their nutrient resources. Moreover, nutrient losses from leaching and volatilization are inevitable.

At the micro level of the individual farm, such a system can appear environmentally attractive. At the macro level of national and global agricultures, given the present levels of population, urbanization, and socio-economic organization, it would be disastrous. In the case of developing countries, where “land hunger” is often acute, it needs to be pointed out that vast areas rely on animal manure for *fuel*, thus burning off their organic nitrogen into the atmosphere.

A girl has collected dried cow dung for use as a fuel. India. (FAO)



The recovery, treatment and recycling of *human* wastes is another possibility. Treated sewage can be used in limited amounts in agriculture. But this poses special problems relating to the need to eliminate pathogens and toxic substances. The long-term use of treated sewage at high rates of application would require treatment processes which are currently uneconomic.

For all these reasons, it would be quite misleading to claim that organic nutrient sources could replace a large share of modern, fertilizer-oriented agriculture. This is not to deny the virtue, and indeed the necessity, of integrating organic manures, fertilizers and leguminous plants within comprehensive plant nutrition systems. Properly managed, integrated plant nutrition systems, designed for local circumstances, are the key to sustained soil fertility.

13.2. Food quality and soil pollution

The quality of food may relate to its appearance, nutritional content or taste. Fertilizers do not affect the *appearance* of food, except in so far as they affect the healthy growth of crops. But they do affect its nutritional content. Whether adversely or beneficially depends again on whether they are used correctly or incorrectly.¹⁶

Potassium deficiency symptoms in soybeans. (Potash & Phosphate Institute)



They may also affect its taste by influencing its chemical composition - its acidity or sweetness, for example, or its texture and physical structure. Taste preferences are clearly highly personal and subjective.

Fertilizers are intended to correct natural imbalances or deficiencies in plant-available soil nutrients. Such correction changes the quality of the resulting produce. For example, as the nitrogen supply increases, the content of protein and some of the vitamins tends to increase, whilst vitamin C and sugar content may decrease. A good phosphorus supply enhances root development, drought resistance, plant growth and ripening - all affecting the final quality of the food. Potassium enhances certain vitamin and mineral contents, texture, firmness and resistance to transport damage.

The *balance* between the uptake of each element also affects produce quality. Trace element deficiencies can harm food quality. The combination and quantities of nutrients giving the best food quality are not necessarily the same as those giving the maximum crop yield - neither are they necessarily different.

Nutrients in organic forms must first be mineralized by natural soil processes before they become available to plants. Consequently, plants do not distinguish between an organic source of a particular nutrient element and inorganic sources such as mineral fertilizers.

As previously noted, some fertilizers may contain trace amounts of elements which are toxic, if absorbed by the body above individual tolerance limits. In the soil, they can be mineralized in the same way as nutrients and are then partially absorbed by plants and taken into the food chain. The body accumulates some and excretes the remainder. Thus manure and human wastes may contain as much or more of such toxic elements as fertilizers and may, in addition, harbour dangerous pathogens. These toxic elements are naturally present in all soils.

In some countries industrial wastes are used as sources of micronutrients. The US

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Environmental Protection Agency has stated that “the Agency continues to believe that some wastes can be beneficially used in fertilizers when properly manufactured and applied.”¹⁷

13.3. Ground water pollution

Fertilizer nutrients applied to the soil are not entirely taken up by crops. Some nutrients remain in the soil, gradually building up a reserve of fertility for the benefit of future harvests. Some runs off the land as a result of erosion and heavy rainfall. Some is lost to the atmosphere through denitrification and volatilization. And some is leached through the soil into ground waters. This applies equally to nutrients mineralized from the soil's natural reserves and from organic manures, except that fertilizers are usually in a fairly soluble form, whereas the process of solubilization of nutrients in organic forms is slow, proceeds throughout the year, and peaks at times which may not be related to crop needs. To this extent, nutrient losses from mineral fertilizers are more controllable than those from organic sources.

Nutrient leaching to ground waters mainly concerns nitrogen. Normally, soluble phosphate compounds are rapidly converted into less soluble forms by natural soil processes, and these are not leached. Potassium binds to clay particles, which also reduces leaching. Potassium leaching can occur in light, sandy soils, or wherever clay is not a significant component, or as a result of excessive applications, but potassium as such - at the concentrations found in ground waters - has no adverse health effect, and there is no recommended limit for potassium in drinking water. Mothers' milk has far more potassium than is ever likely to be found in drinking water.

Nitrogen is different. In its mineral nitrate form, it is highly soluble and does not revert to less soluble forms. In the absence of plant cover, or when more nitrogen is applied than the crop can take up, rain will wash nitrate down, eventually into ground waters. Timing and



Sampling of surface waters: research into nitrate leaching. UK (Levington Agriculture)

quantity in relation to the crop are both critical, and the amount of nitrogen available from non-fertilizer sources must also be taken into account.

There are many practices which help to *minimize* nitrate leaching, though some may increase other problems, such as the incidence of diseases and weeds. In any case, the presence of vegetation is essential to minimize nitrate leaching : land which is bare fallow has a greater potential for nitrate leaching than land under vegetation.

Nitrate entering the body is reduced to nitrite, which reduces the oxygen-carrying capacity of the blood. If the nitrate content of drinking water exceeds certain limits, it is thought that health can be adversely affected. With regard to fertilizer nitrogen, concern initially centred on the possibility that it might contribute to infant methaemoglobinaemia. About 3000 cases have been noted world-wide, mostly in the period from 1950 to 1970, when well water was still being widely used for making baby feed. Spinach and carrots can have

high nitrate contents, but infant food production controls have almost eliminated this risk. The disease has virtually disappeared from Western Europe and North America.

Nitrates in water have also been accused of contributing to stomach cancer, but the World Health Organization has concluded that “no firm epidemiological evidence has been found linking gastric cancer and drinking water... but a link cannot be ruled out.” The prevailing view is that, if nitrates contribute to specific ailments, they are only one - a minor one - of numerous other contributory factors.

13.4. Pollution of rivers and coastal waters

Phosphates can contribute to the eutrophication of lakes and rivers, and nitrates to the eutrophication of coastal waters. Eutrophication is over-enrichment of surface waters leading to an excessive multiplication of algae and other undesirable aquatic plant species, with various undesirable consequences. The origin of the nutrients is by no means solely agricultural, but where it is, the causes are mainly soil erosion and run-off, following heavy winds or rainfall.

Whereas phosphorus tends to be the limiting nutrient in inland waters, nitrogen tends to be limiting in estuaries and coastal waters. Coastlines around the North Sea, the Mediterranean and the Gulf of Mexico have all suffered, and the eutrophication of inland waters is always a potential hazard when water renewal is limited. Indeed, poor water exchange and oxygen deficient conditions at the bottom of lakes tend to cause algal growth, irrespective of supplementary nutrients from agriculture and other sources. All other things being equal, the more intensive the agriculture, the more significantly it contributes to this problem. However, soil erosion can be minimized by good farming practices, among which are the maintenance of vegetation, no-till, reduced or conservation tillage, mulching, contour ploughing, and so forth. In 1996, US farmers



Crops threatened by the effects of erosion. Bolivia. (FAO)

practised no-till farming on 15%, reduced tillage on 26% and conservation tillage on 35% of their planted areas and the proportions continue to increase. Reduced or no-till agriculture, or conservation tillage, reduces labour and energy costs, conserves moisture and enhances soil conservation.

By maximizing vegetation on agricultural land and minimizing the need to use marginal land and woodland for agriculture, fertilizers make a powerful global contribution towards the control and minimization of erosion, soil degradation and deforestation.

13.5. Atmospheric pollution

As far as fertilizer use is concerned, the emission of gases to the atmosphere relates almost entirely to nitrogen, because of the ephemeral nature of nitrogen compounds in the soil. Nitrogen is lost from agriculture not only through leaching but also through volatilization of ammonia and denitrification of nitrate, both resulting from natural processes of decomposition.

Ammonia emissions come mainly from livestock farming. It is estimated that about 40% of the nitrogen ingested by farm animals is lost through ammonia volatilization from animal manures and from the animals themselves. Maturing cereal crops can also contribute significantly to ammonia emissions. However,

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the surface application of urea, especially on calcareous soils, and the practice of injecting ammonia into the soil also result in ammonia losses.

Nitrogen fertilizers account annually for about 4.5 million tonnes of ammonia emissions, which come down with rainfall or as direct deposition, restoring nitrogen and sulphur but, through a series of chemical reactions, acidifying the soil and waters, with adverse effects on ecosystems.

The product of denitrification is usually nitrogen gas, which is inert in the atmosphere. However, in paddy rice production and natural wetlands, methane is produced by the bacterial decomposition of organic materials in the absence of oxygen. Rice paddies are thought to contribute nearly 30% of global methane emissions, but the amount directly attributable to nitrogen fertilizers is probably very small. Methane contributes to global warming. Under anaerobic conditions organic matter can give rise to methane; and it is for this reason that the application of manure to rice paddies during the flooded period is not recommended.

On the other hand, by enhancing plant growth - and hence photosynthetic activity - fertilizer use contributes to the sequestration of carbon dioxide from the atmosphere, thus *reducing* the potential for global warming.

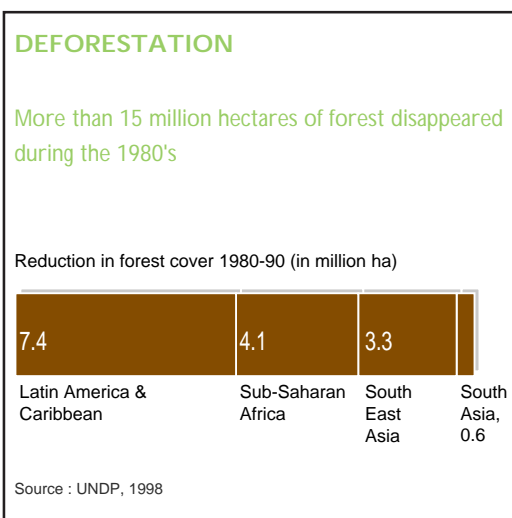
Though the greater part of this sequestered carbon returns back to the atmosphere, greater crop residues lead to more organic matter in the soil, and this increase in organic matter represents a net gain of carbon to the soil - a gain which can be improved by good fertilization and tillage practices.

13.6. Fertilizers and environmentally sustainable agriculture

“The biggest danger to the world’s natural environment today is low-yield agriculture”.¹⁸ Low-yield agriculture means low-input agriculture. Low-input, high-output agriculture is simply not sustainable, whatever methods are used to coax additional nutrients from the soil. Without the additional nutrients supplied by fertilizers, farmers would not have been able to sustain the growing world population without a massive expansion of the agricultural area and a consequent loss of natural habitat; and this would have had incalculably adverse effects on the environment.

In 1960, farmers harvested about 1.4 billion ha. By the 1990s, this was still less than 1.5 billion ha, yet food and feed supplies had been doubled in the interim. If this had not happened, the world would have lost more than 2.6 billion hectares of natural habitat - about the size of North and Central America.

The world’s population has grown exponentially since the early 1800s. A population of one billion people in 1820 grew to 5.7 billion in 1995. According to the World Bank’s population projections, the world’s population will increase from 5.7 billion people in 1995 to 7 billion in 2020, most of the growth occurring in the developing countries. This includes increases in China from 1.2 to almost 1.5 billion, in South Asia from 1.3 to 1.9 billion, and in Africa from 0.7 to 1.3 billion. The rate of increase is likely to be highest in Africa but in view of the large population base in South





Women play an important role in agriculture. Providing them with technical advice and means of production is essential. Indonesia. (PT Pupuk Sriwidjaja)

Asia and China, there will inevitably be a substantial increase in these regions. Globally, the rate of increase is slowing down and by the middle of the 21st century the world's population may have stabilized. It could even begin to decline. In the meantime the world has to face the challenge of providing for a larger number of people and, overall, increased economic affluence.

If still higher yields can produce the food and feed to support this population without using more land, then virtually all of existing wildlife and its habitat, with its irreplaceable food chains and contributions to climate patterns, will have been protected - if the adverse effects of such intensive agriculture can be controlled and minimized. This is *the* major challenge to the environment in the 21st century - teaching farmers to use intensive farming methods *efficiently, without waste, with the least possible adverse effects on the environment and on the health of the populations they feed and clothe.*

Notes

¹⁴ FAO press release, April, 1990.

¹⁵ *The world food situation : recent developments, emerging issues and long-term prospects*, International Food Policy Research Institute, 1997, p.25.

¹⁶ Incorrect use of some fertilizers may also contaminate soil with heavy metals such as cadmium, with adverse effects on food quality - see previous chapter and below.

¹⁷ EPA530-F-97-XXX, Nov. 1997

¹⁸ *Environmentally sustaining agriculture*, Denis T. Avery, The Hudson Institute, pub. *Choices*, AAEEA, 1997.

14. Fertilizers and food supplies

14.1. Trends in agricultural production

Over the last 50 years, humanity has accomplished a feat which, in the previous 50 years would have been unthinkable: it has doubled its population *and* doubled its food supplies. The prospect is for a repetition of this feat over the next 50 years. As for population, short of massive catastrophe or compulsory birth control, there is little that can be done to reduce the forecast increase - though much that *must* be done to prevent its continuation thereafter. As for food supplies, there is everything to be done - and a great and growing debate on how to do it.

Over the last 50 years, the increase in agricultural production has been achieved mainly by increasing crop yields: the agricultural area has expanded relatively little. In 1960, the global area under arable and permanent crops was about 1.4 billion ha. By 1990, this had expanded by just 3.5% to 1.48 billion ha. In 1960, world cereal production was about 830 million tonnes.¹⁹ By 1990, this had increased to 1820 million tonnes - and by 1997,

Farmer tilling a rice field with oxen in Singaraja in the north of the Island of Bali. There are four rice harvests a year. (FAO)



Market. Guinea. (FAO)

to 1910 million tonnes. In addition to supplying humanity directly with a majority of its dietary requirements, cereals have also fuelled the large increase in meat consumption by providing animal feed. Yield increases have accounted for the overwhelming majority of the production increases of the major cereals.

Moreover, agricultural production has generally grown faster in the developing countries than in the developed countries, though from a much lower yield base.

New technologies - improved plant varieties, fertilizers and plant protection chemicals - have been largely responsible for the growth in crop yields, together with an expansion of irrigation and multi-cropping - increasing the number of crops taken annually from the same land. On the other hand, faster population growth in developing countries has meant that they have achieved only a small gain in food availability per capita, and this has been very unequally distributed. Africa, in particular, has seen a declining food availability per capita, and many

African countries face a bleak future unless this trend can be reversed.

In the past, the balance between population and food supplies has been maintained by a combination of natural resource depletion and technological innovation. It is certain that, in its present form, relying for energy as it does on fossil fuels, this balance cannot be maintained indefinitely. As Nobel laureate Norman Borlaug, one of the architects of the Green Revolution, has said, *“for too long, agricultural scientists have left the impression with the general public and political leaders that the growing worldwide demands for food can be coped with indefinitely. We cannot understand those futurologists whose main preoccupation seems to be to prove that new technology will forever disprove the Malthusian thesis.”*²⁰

14.2. The key role of fertilizers

The “Green Revolution” has often been attributed to the discovery and use of high-yielding varieties of cereals which could flourish in the tropical and sub-tropical conditions of developing countries. These new cereal varieties were introduced in the 1960s. Before this, the developed countries had had their own “Green Revolution” after a century of stagnating yields, which largely explains why, in the 1960s, they were already using much more fertilizers than the developing countries. High-yielding plant varieties give high yields *only* if they can extract more nutrients from the soil than lower yielding varieties. Some environmentalists appear to claim that relatively high outputs can be obtained from low inputs. If this signifies high crop yields from low nutrient inputs, it is highly misleading. Low nutrient inputs cannot sustain high crop yields for longer than the time it takes to exhaust the soil. When the soil is exhausted, the output is also exhausted. There is no such thing as sustainable, low-input, high-output agriculture, at least where plant nutrition is concerned.

Just as manures and fertilizers supplement inadequate soil nutrient mineralization, irrigation supplements inadequate rainfall. In many situations, fertilizers and irrigation are complementary - neither can be used economically, or at least to their full potential, without the other. Of course, this also applies to other components of intensive agriculture, for these components are all interactive - their combined effect is potentially greater than the sum of their individual effects. If the result is a higher yielding crop, this translates into a greater amount of nutrients extracted from the soil.

Consequently, with regard to the trends of the last 50 years, “in a sense, the other technologies, such as higher-yielding varieties and irrigation, simply facilitated the greater use of fertilizer” and this was both necessary and providential, because “the frontiers of agricultural settlement had largely disappeared by the middle of this century”.²¹ As shown above, the world’s farmers were able to grow about one billion tons more cereals in 1990 compared with 1960. If they had done that at the yield levels of 1960, they would have had to use 120% more cropland - in fact, nearly 700 million hectares more. This, of course, presumes that 1960 yields *could* have been maintained on such a vast area of additional cropland. Since farmers naturally use their best

Higher yields are necessary to satisfy increasing cereal demand without harming marginal land.
(Norsk Hydro A.S.)



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land first, much of this additional land would have been of marginal quality, easily degradable, relatively inaccessible and much more environmentally sensitive. To maintain 1960 yields on such land would certainly have entailed massive use of fertilizers and other inputs, as well as huge infrastructural investments.

In 1960, the world's farmers cropped about 1.4 billion ha. According to the Hudson Institute, "if the Green Revolution had not more than doubled the yields on the world's best farmland, the world would already have lost more than 10 million square miles (2.6 billion ha) of habitat - about the land area of North and Central America".²²

The level of fertilizer use and its rate of growth are good indicators of progress in the implementation of high-input technologies. During the 30 years from 1960 to 1990, fertilizer use in the *developed* countries increased from 26 to 73 million tonnes.²³ In the *developing* countries, however, the increase was from a mere 4 million tonnes to 65 million tonnes; and with the collapse of the agricultural system in the countries of the former Soviet Union and Central Europe, the developing countries' fertilizer use had surpassed that of the developed countries by 1992.

World fertilizer consumption

million tonnes N + P₂O₅ + K₂O

	1960/61	1990/91	1996/97
OECD countries	20	45	46
Central Europe / FSU*	6	28	8
Total developed countries	26	73	54
Developing countries	4	65	80
World	30	138	134

* USSR / Former Soviet Union

However, the disparities in the intensity of fertilizer use between different countries and regions is disturbing. Some examples are given in the following table.

Average rates of application
of N + P₂O₅ + K₂O

	Rate Kg nutrients per ha
Wheat — France	240
Russia	25
Rice — Korea Rep.	320
Cambodia	4
Maize — USA	257
Tanzania	12
Cotton — Tadjikistan	461
Benin	45

Source : Fertilizer Use by Crop. FAO/IFA/IFDC. 1996

The International Food Policy Research Institute has projected a global increase in cereals demand of 41% between 1993 and 2020. Similarly, it forecasts a 63% rise in meat demand and a 40% rise in demand for roots and tubers.²⁴ The developing countries will account for 80-90% of these increases, with sub-Saharan Africa experiencing the largest demand increases (100-150%). More than 90% of this additional food is forecast to come from higher crop yields, though higher agricultural prices would provide some incentive to make the high capital investments needed to develop new agricultural land. However, much of the *existing* farmland also needs massive infrastructural investments to bring it within reach of modern agriculture; and increasing food prices in poor developing countries is politically unattractive.

Consequently, if crop production is to rise to meet this demand, fertilizer use must also rise, irrespective of what new technologies may emerge. This would be not simply in order to increase yields on existing cropland whilst sustaining its soil fertility, but also to preserve

the natural habitat from the ravages induced by the agricultural exploitation of unsuitable land.

The International Food Policy Research Institute argues that there are significant linkages, particularly in Africa, between armed conflict and environmental degradation, natural resource scarcities and food insecurity²⁵.

14.3. Fertilizer use by crops

Analysts and others world-wide have long been interested in making comparisons of fertilizer use between countries and regions. One of the most common ways of doing this is to divide total consumption of fertilizer in a country or region by measures of land area such as the hectares of arable land or by the hectares of arable land and land in permanent crops. However, none of these aggregated statistics indicate how individual crops are fertilized in different countries. It is difficult to compare application rates of countries that have large areas of permanent crops such as oil palm, rubber, citrus, coconut, fruit and nut trees, cocoa, coffee, tea, etc., with those that do not. Statistics for countries that produce a large share of their crops as vegetables or sugarcane, that are fertilized heavily, do not indicate how the remaining crops are fertilized. Cropping intensity, for example as practiced in Egypt, also influences averages, as does the percentage of arable land under irrigation. In some countries in Western Europe and in Oceania, a large amount of permanent pasture/grassland is fertilized and, because this is not counted as arable land, dividing total fertilizer use by the arable area gives misleading results - double or more than double the actual rates in some countries.

In 1992, IFA, FAO and the International Fertilizer Development Center (IFDC) decided to conduct a survey to rectify this problem. Detailed statistics on the use of fertilizers on individual crops are collected in the United States and the United Kingdom, but rarely elsewhere. Hence the survey had to be based on

Estimated world fertilizer usage by crop grouping

% of world usage			
Wheat	20	Fruits and vegetables	5
Corn	14	Sugar	4
Rice	13	Fibres	4
Barley	4	Other crops *	3
All other cereals *	4	Pasture / hay *	11
Oilseeds	12		
Roots and tubers *	6	Total	100

Source : G. Harris. An analysis of global fertilizer application rates for major crops. IFA Annual Conference, Toronto, May 1998.

* Oats, milo, millet, rye, triticale and teff

* Primarily potatoes

* Includes cocoa, coffee, tea, tobacco and pulses

* Includes grassland, fodder, silage, etc...

knowledgeable estimates. The estimates are believed to be reliable but they should be used to reflect the general magnitude of usage by a crop rather than an exact measurement.

It is also difficult to expand the results of the survey data to regional and world totals because the countries that responded were not randomly selected and probably have higher application rates than those that did not respond. Although the sample indicates that 65% of the fertilizer was used by cereals, a higher percentage of global cereals area was included in the survey than in the case of other crops. Adjustments were made to take account of such factors and the results are given in Table 3. This method indicates that wheat is the largest user of fertilizers world-wide and that cereals use approximately 55% of the world's fertilizer. The next largest users are oilseeds and pasture/hay.

The world cereal area has declined from 717 million ha in 1986 to 695 million ha in 1995. During the same period, the world's oilseed area has grown from about 126 million ha to 155 million ha. The demand for vegetable oil and many other uses for oilseeds has caused the area to expand. The growth of the animal feed sector in developing countries has also had a major impact on the growth in oilseed area. Changes in cropping patterns such as this can have an important impact on the total consumption of

14. Fertilizers and food supplies

each nutrient as well as the average application rates in each country.

The reported information indicates that, after cereals and oilseeds, fertilizer usage is relatively evenly split between vegetables, sugars, roots/tubers, and fibers. The crops with the highest application rates per hectare, all above 200 kg total nutrients per hectare, are bananas, sugar beet, citrus, vegetables, potatoes, oil palm, tobacco, tea and sugarcane.

14.4. Organic manures

The restoration of soil nutrients necessitated by the high crop yields needed to support the present and future world population cannot be achieved by organic manures alone. In the present circumstances, and *a fortiori* in the future, sufficient economic agricultural production can only be achieved with mineral fertilizers. Organic materials have an unstable, uncertain and much lower nutrient content than fertilizers. They are extremely sensitive to transport and handling costs; and depending on their origin they can contain potentially harmful levels of elements such as lead, cadmium and arsenic.

For lack of alternative fuels, animal excreta are generally burned in many Asian and African countries, and also in parts of Latin America. For socio-cultural reasons, the use of human night-soil is not widely practiced, except in

Preparation of compost. France. (Société Commerciale des Potasses et de l'Azote)



China. However, the *fermentation* of animal and human excreta to form biogas for domestic fuel is a promising alternative to simple combustion, since the resulting slurry can be used as manure with reduced loss of nutrients. Cheap fermentation units have been developed, and if they could be successfully promoted wherever manures are currently burned, the contribution to soil fertility would be locally very significant. But in the context of future world food supplies, quite apart from the economics of organic manure distribution, there is simply not enough organic material to provide the necessary nutrients.

Nevertheless, organic manures and mineral fertilizers can often be used together - and should be so used whenever it is physically and economically possible and environmentally desirable. As the conflict between global population, energy use and agricultural ecology tightens during the coming decades, it will become increasingly necessary to integrate all available economic nutrient sources within efficient systems of plant nutrition and crop management.

14.5. Biological nitrogen fixation

Much research is devoted to the chemistry and genetics of biological nitrogen fixation. The objectives are to improve strains of nitrogen-fixing bacteria, to extend the range of symbiotic relationships between nitrogen-fixing bacteria and plants and, eventually, to breed non-leguminous plants that can fix their own nitrogen. For example, it may be possible to develop cereals with the ability to fix nitrogen in their leaves. But in order to function, the nitrogen-fixing enzyme needs anaerobic (oxygen free) conditions on the microscale. Whether such conditions can be engineered in crop plants remains doubtful. Optimism for early solutions to such biotechnological problems has so far proved to be unfounded, especially since the development of new plant varieties is such a slow process.

In rice cultivation, the use of azolla has significantly augmented nitrogen supply in some Asian countries. Azolla is a water fern which lives in symbiosis with cyano bacteria which fix nitrogen. However, azolla alone does not produce the large nitrogen inputs required by the most productive rice varieties. Moreover, it needs substantial amounts of phosphorus for its own growth. It is unlikely that azolla will make much difference to the need for nitrogen fertilizers in intensive rice cultivation.

Some nitrogen-fixing bacteria can live in association with the roots of grasses, contributing to the nitrogen supply of the plants. This can be locally important for some grassland under special circumstances, but the amount of nitrogen fixed is small.

Another possibility is the development of bacteria to convert plant residues in the soil to ammonia. However, the extensive distribution of such bacteria is unlikely to be practical, because the environmental consequences of the spread of such bacteria in nature might be dramatic.

Consequently, for the time being, fallowing, the use of leguminous crops in crop rotations, and the alternate cultivation of temporary grassland and cropland remain the only way for farmers to augment soil nitrogen biologically.²⁶

N is fixed by bacteria in nodules on roots of soybeans and other legumes. (Potash and Phosphate Institute)



Field trials on fertilizers and azolla. (Philippine Phosphate Fertilizer Corp.)

The view that nitrogen fertilizers may ultimately become obsolete is not yet supported by scientific knowledge, and the impact of biological nitrogen fixation is likely to be negligible for the foreseeable future.

Notes

¹⁹ Rice counted as paddy.

²⁰ *Fertilizer: to nourish infertile soil that feeds a fertile population that crowds a fragile world*, N. Borlaug and C.R. Dowsell, 61st IFA Annual Conference, 1993.

²¹ *Future supplies of land and water are fast approaching depletion*, Lester R. Brown, in *Population and food in the early 21st century*, ed. N. Islam, pub. IFPRI, 1995, p.165.

²² *Environmentally sustaining agriculture*, Denis T. Avery, Hudson Institute, pub. in *Choices*, AAEEA, 1997.

²³ Nutrient content: $N+P_2O_5+K_2O$.

²⁴ *The world food situation: recent developments, emerging issues and long-term prospects*, P. Pinstrup-Andersen et al, IFPRI, 1997.

²⁵ *Food from Peace. Breaking the Links between conflict and Hunger*, E. Messer, M.J. Cohen and J. D'Costa, IFPRI, 1998.

²⁶ Asymbiotic bacteria also fix nitrogen in the soil, and atmospheric nitrogen deposits make a contribution, but these are not agriculturally controllable.

15. The promotion of fertilizer use

15.1. Spreading the message

The adoption of fertilizer use as a regular farming practice generally occurs in three stages:

- 1 The introductory period, when only the most progressive farmers use fertilizers;
- 2 The “take-off” stage when the number of fertilizer users and the rates of use grow quickly;
- 3 The mature stage when the large majority of farmers use fertilizers at rates which no longer grow rapidly.

The time required to pass from one stage to the next can vary, usually from one to several decades. Strategies to compress the introductory stage are essential. Specific government action directed to this end must be vigorously pursued and supported by appropriate policies.

The introduction of fertilizer use depends on creating interest and awareness among farmers, as well as confidence in local advisory agencies. Equally important is the establishment of farmers’ confidence in adequate, stable prices, a timely fertilizer supply system, and efficient, accessible credit and marketing arrangements.

The interest and awareness is created by demonstrating the effect and profitability of applying fertilizers in normal farming conditions. These demonstrations can be complemented by farm meetings and visits, class instruction, and programmes on radio and television. A nationwide fertilizer information campaign is an essential feature, supported by local field experiments. The results must be transmitted to farmers not only by advisory services but also by fertilizer dealers.

Mineral fertilizer use must be publicly recognized as the spearhead of agricultural development - the first step on the way from traditional subsistence farming to modern

intensive crop production. “No country has been able to increase agricultural productivity without expanding the use of chemical fertilizers.”²⁷ Its promotion must be a priority goal of developing governments.

15.2. Supporting the messengers

Farmers everywhere are extremely averse to risk. Their confidence in local advisors and fertilizer dealers is absolutely essential. This requires a continuing government commitment to financing the recruitment and training of suitable staff and the maintenance of supporting institutions.

These institutions must include not only the advisory services but supporting agricultural research services with activities correctly focused on the practical problems encountered at farm level. Fertilizer use must be monitored scientifically and eventually integrated within a package of other practices if it is to remain effective and not environmentally harmful. In the words of the FAO, “some developing countries are encountering difficulties in increasing yields in spite of increasing doses of fertilizers. The efficiency of fertilizer use is often quite low as a result of incorrect timing and poor application methods or failure to maintain the balance between the main nutrients, secondary nutrients and micronutrients. Soil toxicity caused by salinity, alkalinity, strong acidity, aluminium toxicity and excess organic matter also prevents the full benefits of fertilizer use from being realized. Crop and nutrient management at plot, farm and village level will have to become increasingly sophisticated to ensure that the lack of one component does not invalidate the use of the entire package.”²⁸

Fertilizer recommendations must be simple. Compound or multi-nutrient fertilizers can help to reduce the number of recommended fertilizers and promote reasonably balanced usage between the different nutrients. The local fertilizer trade must be regulated and supervised to prevent fraud and maintain proper competition; but it must also be provided with adequate incentives to operate profitably.

Matters affecting national fertilizer use are sometimes decided in several different government ministries. This invites contradictions and lack of coordination. Ideally, all fertilizer policy matters should be concentrated within a single ministry or secretariat. An active process of consultation between the various interested parties within the government, and between the government and the private sector, should be institutionalized.

Fertilizer imports, national production, transportation systems, infrastructural investment and an adequate marketing and distribution network have to be planned long in advance. Fertilizer sales are highly seasonal. It is no use if the fertilizer arrives after the time when it is needed. Sufficient stocks have to be built up during the off-season to meet the peaks in demand, and this means suitable storage to avoid loss by deterioration and pilfering.

IEA-sponsored fertilizer development project, coordinated by FAO's Special Programme for Food Security in Zambia, involves a series of farmer field schools on Integrated Plant Nutrition. A pilot input supply scheme, involving initial credit support for local fertilizer retailers will be implemented.



Moreover, farmers should not be expected to travel long distances to obtain fertilizer.

15.3. Financing fertilizer use

Many developing countries are short of foreign exchange and depend largely or entirely on imports for their fertilizer supplies. This is often exacerbated by falling local currencies and dependence on foreign governmental aid, which, in recent years, has steadily declined. Fertilizer is only one of many claims on available finance, but where food security is in danger, they must be given a high priority, if their efficient use is to be assured. For as costly as fertilizer imports may be, the corresponding food imports would be even more costly; and food imports can be a powerful constraint on the national agricultural economy and a depressing disincentive for local farmers.

At the village level, millions of small farmers face the same problem - lack of finance to buy inputs, without which they can improve neither their output nor their profitability. Subsidies may keep the fertilizer/crop price ratio favourable, but without credit the farmers cannot afford to buy the inputs they need. Credit schemes are an essential element in promoting fertilizer use.

The quality of credit is as important as its volume. Not only does it have to be affordable, but it requires efficient supervision and integration with the agricultural marketing system and the technical services. It also has to be organized in a way which ensures high rates of repayment and an awareness among farmers of their mutual interest in respecting their credit obligations.

Notes

²⁷ M.S. Swaminathan, *The Observer*, New Delhi, 17-4-97.

²⁸ *World Agriculture Towards 2010*, FAO.

16. Government, farmers and industry - partners in food security

Throughout this book we have tried to make three things apparent :

1. Fertilizers, and hence the fertilizer industry, constitute, and will continue to constitute, one of the most important keys to world food supplies - though by no means the only one. The more nutrients are taken out of the soil by crops, the more have to be put back : there is no substitute for plant nutrients. And the more people there are on this planet, the more food they will eat. For reasons relating to the various nutrient cycles - but especially the nitrogen cycle - there is simply not enough organic material to sustain soil nutrient levels, and hence soil fertility - not even if all the world's animal and human excreta could somehow be collected and recycled to agricultural land.
2. The fertilizer industry and its associated trades comprise a complex network of suppliers and buyers of numerous different raw materials, intermediates and finished products, and this creates a high degree of international interdependence. Over the last few decades, primary production has tended to concentrate near the major sources of raw materials and feedstocks; and, as smaller sources of these materials become exhausted or uneconomic, this trend will continue, producing still greater geopolitical interdependence and division of responsibilities for the prosperous survival of planet Earth.
3. The responsibility of governments for ensuring food security will grow proportionately with the growth of populations; and governments in developing countries bear a special responsibility for promoting and distributing agricultural inputs, including fertilizers. They cannot do this effectively without the confidence of farmers and the fertilizer industry - all three parties are in a partnership, without which their objectives will fail.

The world fertilizer industry has an outstanding record of technical improvement of its products and production processes. Since its beginning, more than 150 years ago, the fertilizer industry has contributed towards the promotion of fertilizer use wherever circumstances permit the prospect of a successful outcome. The fertilizer industry has a "duty of care" in the legitimate, efficient use of its products by farmers. Evidently, it is not possible for the industry to have a direct influence on the billions of farmers throughout the world. But the fertilizer industry acknowledges its responsibility, together with other industry groups, to promote an efficient, economic, environmentally-conscious use of

fertilizers, and to ensure that the relevant scientific information is made available. Through IFA, the industry can endeavour to improve public understanding of its own problems and prospects. We hope that this book will assist in this endeavour.

If the rising tide of population is to be adequately fed, immense political goodwill and widespread public interest in the problems and issues concerning world food supplies will be required. In the final analysis, the growing conflict between humanity and the environment cannot be allowed to bear more adverse consequences for humanity than for the environment, since the two are interdependent.

As the future unfolds, we are convinced that fertilizers will become *more*, not less important in ensuring world food supplies. In the words of Norman Borlaug, “let us all remember that world peace will not - and cannot - be built on empty stomachs. Deny farmers access to modern factors of production - such as improved varieties, fertilizers and crop protection chemicals - and the world will be doomed, not from poisoning, as some say, but from starvation and social chaos.”

To sum up, we may quote the words of HRH Prince Philip, Duke of Edinburgh, to the 50th Anniversary Conference of the International Fertilizer Industry Association: “It is the job of farmers to grow food, but the level of their productivity and the quality of their produce depend to an ever increasing extent on sound scientific advice, efficient and reliable equipment, the regular supply of the best seeds, fertilizers and pesticides and, above all, on the sympathetic encouragement of their governments.”

Appendix 1 : Contact organizations

IFA - International Fertilizer Industry Association

IFA, the International Fertilizer Industry Association, comprises around 500 member companies in over 80 countries. The membership includes manufacturers of fertilizers, raw material suppliers, regional and national associations, research institutes, traders and engineering companies.

IFA collects, compiles and disseminates information on the production and consumption of fertilizers, and acts as a forum for its members and others to meet and address technical, agronomic, supply and environmental issues.

IFA liaises closely with relevant international organizations such as the World Bank, FAO, UNEP and other UN agencies.

IFA's mission

- To promote actively the efficient and responsible use of plant nutrients in order to maintain and increase agricultural production worldwide in a sustainable manner.
- To improve the operating environment of the fertilizer industry in the spirit of free enterprise and fair trade.
- To collect, compile and disseminate information, and to provide a discussion forum for its members and others on all aspects of the production, distribution and consumption of fertilizers, their intermediates and raw materials.

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UNEP - United Nations Environment Programme

UNEP's Industry and Environment centre in Paris was established in 1975 to bring industry, governments and non-governmental organizations together to work towards environmentally-sound forms of industrial development. This is done by:

- Encouraging the incorporation of environmental criteria in industrial development.
- Formulating and facilitating the implementation of principles and procedures to protect the environment.
- Promoting the use of low- and non-waste technologies.
- Stimulating the worldwide exchange of information and experience on environmentally-sound forms of industrial development.

The Centre has developed a programme on Awareness and Preparedness for Emergencies at Local Level (APELL) to prevent and to respond to technological accidents, and a programme to promote worldwide Cleaner Production.

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Washington, D.C. 20006

United States

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FAO - Food and Agriculture Organization of the United Nations

Land and Water Development Division

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Email: land-and-water@fao.org

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PPI - Potash & Phosphate Institute

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Norcross, Georgia 30092-2837

United States

Tel: 770-447-0335

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Email: ppi@ppi-far.com

Web: <http://www.agriculture.com/ppi/index.htm>

IFDC - International Fertilizer Development Center

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