Mineral Fertilizer Use and the Environment

International Fertilizer Industry Association
United Nations Environment Programme

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Fertilizer Use and the Environment
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International Fertilizer Industry Association
Revised edition. Paris, February 2000.

The help of Mr. A.E. (Johnny) Johnston, IACR-Rothamsted, U.K., in reviewing and correcting the text is gratefully acknowledged.

ISBN: 2-9506299-3-8

The text of the document is available on IFA's Internet site.

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Printed in France.
Layout: Claudine Aholou-Pütz, IFA

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Preface

This document aims to present a balanced view of, on the one hand, the benefits of using mineral fertilizers and on the other hand the environmental risks involved. It is not intended to be a scientific document, but it aims to be technically correct.

Chapter 14 of **Agenda 21**, agreed at the UNCED "Earth Summit" held in Brazil in 1992, states *"The world's capacity to feed a growing population is uncertain ...agriculture has to meet the challenge mainly by increasing food production on land that is already in use, and avoid encroachment on land that is only marginally suitable for cultivation"*.

This review presents the evidence supporting the view that the use of mineral fertilizers is a necessary condition for achieving these objectives. Their use is necessary but they do have an impact on the soil, water, air, plant and human health.

All human activities affect the natural environment either adversely or beneficially; and what is adverse or beneficial may depend 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 while retaining benefits. The *use* of fertilizers is no exception, but both the policy maker and the farmer must have the necessary knowledge. Farmers must know how to use fertilizers efficiently under their own particular circumstances. Most of the adverse effects of fertilizer use result from inadequate knowledge among farmers.

The review highlights the importance of using mineral fertilizers efficiently. Inefficient use not only increases their negative environmental impact unnecessarily, but also represents a large waste of natural resources and a substantial economic loss.

To improve the efficiency of fertilizer use is a major challenge. There is also scope for improved products, but the greatest medium-term gain could be had from improving the way in which currently available fertilizers are used. Many techniques for achieving this are known, but often they are not put into practice. The task of communicating information on the correct techniques to farmers, and of persuading them to adopt them, is formidable. Of the world population of 5.7 billion in 1995, the agricultural population accounted for 2.6 billion.

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Note: *In this document:*

- Mt = million tonnes
- Kt = thousand tonnes
- Mha = million ha
- Phosphate and potash may be expressed as their elemental forms P and K, or as their oxide forms, P_2O_5 and K_2O. Nitrogen is expressed as N.

1. An introduction to mineral fertilizers

1.1. What are fertilizers

Mineral fertilizers are materials, either natural or manufactured, containing nutrients essential for the normal growth and development of plants. Plant nutrients are food for plants some of which are used directly for human food, others to feed animals, supply natural fibres or produce timber. Man and all animals depend entirely on plants to live and reproduce. The public perception of mineral fertilizers often takes no account of these simple facts.

Three plant nutrients have to be applied in large quantities, nitrogen, phosphorus and potassium. Sulphur, calcium and magnesium also are required in substantial amounts. These nutrients are constituents of many plant components such as proteins, nucleic acids and chlorophyll, and are essential for processes such as energy transfer, maintenance of internal pressure and enzyme action. Seven other elements are required in small or trace quantities and are referred to as “micronutrients” or “trace elements”. A further five elements are required by certain plants. These elements have a variety of essential functions in plant metabolism. The metals are constituents of enzymes controlling plant processes. The deficiency of any one nutrient can compromise the development of the plant.

Mineral fertilizers comprise naturally occurring elements which are essential to life. They give life and are not biocides. Fertilizers are used in order to:

- supplement the natural soil nutrient supply in order to satisfy the demand of crops with a high yield potential and produce economically viable yields,
- compensate for the nutrients lost by the removal of plant products or by leaching or gaseous loss,
- improve unfavourable or to maintain good soil conditions for cropping.

The existence of a close relationship between fertilizer consumption levels and agricultural productivity has been established beyond doubt. Amongst the various agricultural inputs, fertilizers, perhaps next only to water, contribute the most to increasing agricultural production.

In this publication, the term “mineral” fertilizer is used in preference to terms such as “chemical”, “artificial” or “synthetic” fertilizers. Apart from nitrogenous fertilizers, they are, in fact, more or less purified minerals. In the case of nitrogen, approximately 99% of the total supply is produced from ammonia, which is manufactured from the abundant atmospheric nitrogen reacted with hydrogen.

1.2. Where are fertilizers used?

The use of fertilizers as a regular farming practice began in most European countries in the mid to late nineteenth century but the greatest increase in consumption in these countries occurred in the three decades following World War II. Their increasing use in the developing countries started in the 1960s.

In 1960, 87% of the world fertilizer consumption was accounted for by the developed countries, including the USSR and the countries of Central Europe. From 1980 to 1990 consumption tended to stabilize in these regions, apart from the USSR, where it increased until 1988. Population growth had leveled off, almost everyone was adequately fed, world agricultural exports had stagnated due to economic problems in the importing countries and on well managed farms the economic optimum of the available varieties had been reached.

Between 1989 and 1994 fertilizer consumption in developed countries as a whole fell from some 84 Mt nutrient in 1988 to 52 Mt nutrient in 1994. The fall was greatest, by 80% in total, in the formerly communist countries of Central Europe and the former Soviet Union (FSU). Crop production in this region also fell, although not to the same extent. This was because under the centrally planned system fertilizers were used inefficiently and plant available reserves of some nutrients had accumulated in the soil and could now be mined to help feed crops.

In developing countries until the 1960s fertilizers were applied mostly to plantation crops such as tea, coffee, oil-palm, tobacco and rubber, while application to field crops was either small or non-existent. Even where fertilizers were applied, application rates had to be small in view of the traditional tall cereal varieties which were cultivated at that time. The introduction of high-yielding, fertilizer-responsive dwarf varieties in the mid to late sixties gave a considerable boost to fertilizer consumption applied to annual field crops. Unfortunately this development has still not occurred in many countries of sub-Saharan Africa, for economic and climatic reasons and also for lack of suitable varieties.

Since 1960, fertilizer consumption in the developing countries has increased more or less continuously, and today accounts for about 60% of the world total, compared with 12% in 1960, a trend which is continuing. With their rapidly increasing populations, many developing countries are compelled to give agricultural production and the development of fertilizer use a high priority.

Between 1993/94 and 1997/98 world total fertilizer nutrient consumption increased from 120 to 136 Mt, an average rate of increase of about 3% p.a. Consumption in China, South Asia and Latin America increased by 10, 5 and 2 Mt respectively. But in most countries of sub-Saharan Africa the quantity of fertilizer used is not only very low, but also most of what is used is applied in the commercial, plantation sector. Rates of fertilizer use on food crops are particularly low. There is a very large variation in application rates between countries, as is shown by the examples in the following table.

Average rates of application of N + P_2O_5 + K_2O

		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

Rates of fertilizer use in the Russian Federation have fallen greatly since 1989.

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

1.3. Where are fertilizers produced

Increasingly the manufacture of fertilizers is a global industry, located near the source of the raw materials or in developing countries with expanding markets for the products. Fertilizer production is decidedly not a monopoly of the developed world.

1.3.1. Nitrogen fertilizers

The energy required for nitrogen fertilizer production is found around the planet and there is production in every region of the world. However, there has been a trend towards increased production not only in locations where cheap natural gas is available, such as the Middle East and the Caribbean, but also in the main consuming regions, such as South Asia and China.

1.3.2. Phosphate

The main producers of phosphate rock and phosphate fertilizers are the USA, the FSU, China, Africa and the Middle East. Several of these countries are developing countries and the phosphate industry makes an important contribution to their economies.

Over the past two decades there has been a distinct trend towards the processing of phosphate rock in countries with substantial natural resources of this material, especially in North Africa and the USA, but also in the Middle East and South and West Africa. There have been several plant closures in West Europe, where phosphoric acid production capacity and output have fallen by 60% since 1980, for economic and environmental reasons, particularly the problem of gypsum disposal.

1.3.3. Potash

Potash is produced in the few countries where the ores are located. In 1996 Russia and Belarus accounted for 23% of the world's production, Canada for 35%, West Europe for 23% and Israel and Jordan for 11%, these few regions thus accounting for a total of 92% of world production.

2. What if?

What would happen if mineral fertilizers were not used?

The immediate effect of terminating the use of mineral fertilizers is that crop yields would fall to levels sustainable by the soil alone and the relatively small net inputs through organic materials, and that the yields would fall progressively as the soil nutrient reserves are used up, declining eventually to the low levels observed in very long-term trials. In the absence of fertilizers it is likely that cropping systems and management methods would change, but despite all the efforts, it is inevitable that the present structure and output of agriculture could not be maintained. There would simply be insufficient crop nutrients in the overall system. The richer countries may possibly get by but not the poorer countries, and perhaps not the poor in richer countries.

Schmitz and Hartmann (1994) established models to make quantitative estimates of the effect of reducing the use of agro-chemicals, including nitrogen, in Germany. They calculated that halving the fertilizer nitrogen application would lead to a 22% reduction of yields in the short-term, 25 to 30% in the medium term, farm profits reduced by about 40%, farm income by 12%, total cereal production reduced by 10%, with a substantial impact on employment in agriculture and the food processing industries, reduced agricultural exports, increased imports, and an increase of the world price of cereals of 5%. For limited reductions in nitrogen use, some ecological benefits would be obtained rapidly but, with across-the-board extensification, the gains would fall and even turn into losses, with a reduction in woodlands and wetlands as these were brought into cultivation. If this is the position in Germany, what should it be in less industrialized countries?

In France in 1850 the average wheat yield was 1000 kg/ha. By 1950 it had reached 1600 kg/ha with a fertilizer consumption of 1.1 Mt total nutrient. By 1973 the average yield was almost 4500 kg/ha, fertilizer consumption 5.8 Mt nutrient, of which 1.8 Mt was N. The average yield between 1994 and 1996 was 6772 kg/ha with the consumption of 4.8 Mt nutrient, of which 2.4 Mt was N. In France there has been a close correlation between the production of cereals and nitrogen deliveries. The effect was made possible by the use of a combination of all the means of production, species and varieties with a high genetic potential, grown on well prepared soil, protected against pests and diseases. Annual yield variations were minimized and production costs reduced. At 1950 yields it is estimated that a household would still spend 50% of its income on food compared with 20% today. France is now the second largest world exporter of agricultural and derived products.

It is sometime salutary, when advocating the termination of some technical advance, to look back at the situation before the advance occurred. Price (1993) described the situation in France until the nineteenth century. Prosperity or misery, life or death depended on a good harvest. The last major famine in France was in the early 1700s although “crises de subsistence”, when cereal prices increased by 50% to 150%, continued to occur until the mid 1800s. The crises of 1788-89 and 1846-7 were particularly notable in terms of their economic, social and political impact, both preceding popular revolt.

In China, using organic matter to maintain the fertility of the land, rice yields were maintained at 700 kg/ha for thousands of years. During the past 40 to 50 years, using a combination of available organic materials and an ever-increasing input of mineral fertilizers, yields have multiplied six-fold, to reach an average, between 1994 and 1996, of 5958 kg/ha.

A. Subba Rao and Sanjay Srivastava (1998) wrote *Fertilizers have played a very prominent role in Indian agriculture. From a mere 0.13 Mt in 1955-56, fertilizer consumption has increased dramatically over the last four decades to reach 14.3 Mt in 1996-97. As a consequence of the growing demand for foodgrain, fibre, fuel and fodder to meet the needs of an ever increasing population, fertilizer consumption is increasing annually. The contribution of fertilizers to total grain production in India has been remarkable; from one per cent in 1950 to 58 per cent in 1995. According to M. Velayutham, the contribution of fertilizer to additional food production was about 60 per cent. Fertilizer consumption and agricultural production showed phenomenal growth during the period 1951 to 1995. The present concern is to ensure the sustainability of crop yields, a safe environment and profitability for the poor farmer with increased fertilizer use.*

In general, it is difficult to estimate the contribution of mineral fertilizers to global agricultural production in view of the interaction of the many factors involved in this biological process. An IFA survey covering developed countries carried out in the 1970s indicated that yields would fall rapidly by some 40% to 50% if fertilizers were no longer applied. According to some Chinese data, fertilizers contribute 40% to 50% of the grain yield, 47% of the cotton yield. V. Smil (1999) estimated that, globally, 40% of the protein in the human diet is derived from nitrogen fixed by the Haber-Bosch process for the manufacture of ammonia.

In Japan, A. Suzuki (1997) reports that surveys made in 1990 at 92 experimental sites showed that the national average yield obtained without nitrogen applied for several years was 70% of the fertilized plots. Yields decreased gradually over the years. In a long-term trial, after 50 years of NPK fertilization there was no decrease over the years in the fertilized plots. The yield without fertilizer was about 40% of that of the fertilized plot.

Mackenzie and Taureau (1997) gave a typical yield response curve of winter wheat to fertilizer nitrogen in the UK. Even at the economic optimum, where the value of the additional unit of nitrogen equals the value of the crop obtained therefrom, the response was 3 kg grain per kg N. Without nitrogen the yield would have been 4 t/ha instead of 7 t/ha at the economic optimum. From another series of trials in the UK quoted by the same authors, it was estimated that the yield of wheat increased by 24 kg of grain for every 1 kg of N fertilizers up to the stage where the response started to plateau.

Based on a wide range of experiments in a large number of countries, the FAO considered that "it is reasonable to assume that 1 kg of fertilizer nutrient ($N+P_2O_5+K_2O$) produces around 10 kg of cereal grains" (FAO, 1984).

K.K.M. Nambiar (1994) summarizes results from long-term trials in India, from which the following is an extract:

Yields (kg/ha)	No fertilizers	NPK	NPK + FYM
Rice*	1751	3607	3994
Wheat**	994	3342	3545

* Average of three locations
** Average of four locations

3. The demand for mineral fertilizers

3.1. The future demand for agricultural products

3.1.1. Population

Between today and, say, 2020, the world's population is going to increase, mostly in the developing countries. According to the World Bank's 1994-1995 population projections, the world's population will increase from 5.7 billion people in 1995 to 7 billion in 2020. This includes increases in China from 1.2 to almost 1.5 billion, South Asia from 1.3 to 1.9 billion, Africa from 0.7 to 1.2 billion. The rate of increase is likely to be highest in Africa but in view of the large population base in South Asia and China, there will inevitably be a substantial increase in these regions. IFPRI (1999) estimates that developing countries will account for about 85% of the increase in the global demand for cereals and meat between 1995 and 2020.

FAO projects that 680 million people, 12% of the world's population, could be chronically under-nourished in 2010, down from 840 million in 1990-92 but still a very substantial number. 70% of these will be in sub-Saharan Africa and South Asia, especially Bangladesh.

In Africa and the Near East, the absolute number of hungry people will increase, though the proportion of the population that is undernourished will decline. Many of these people are the rural poor, who lack the buying power to satisfy their nutritional needs, even when the supplies exist. Women and children are most affected. The issue in their case is to develop agricultural systems which will provide them with sustenance and income.

3.1.2. Income

According to the International Food Policy Research Institute (IFPRI, 1997), between 1993 and 2020, the global demand for cereals is expected to increase by 41%. The developing countries' demand for cereals for feeding to livestock is expected to double, while demand for direct human consumption is expected to rise by 47%, although the largest absolute increase will be greater for the latter. There will be similar large increases in the demand for other crops. Global income growth is projected to average 2.7% per year between 1993 and 2020, the growth rate in developing countries being almost twice that of developed countries. Economic growth, rising incomes and urbanization, particularly in Asia and Latin America, are leading to rapid changes in diets, in favour of more grain-intensive food such as meat, particularly red meat. This leads to a substantial increase in the demand for grain to feed livestock, the impact on cereal requirements being magnified by the rather low feed conversion efficiency of livestock. IFPRI (1999) estimates that the world's farmers will have to produce 40% more grain in 2020, compared with 1995. However, the expansion of the cereal area is unlikely to be more than 5%, almost two thirds of which will be in the difficult region of sub-Saharan Africa. Inevitably most of the higher production must come from higher yields per unit area, which will require a correspondingly larger quantity of plant nutrients, from one source or another.

3.1.3. Fertilizers and food

The exact contribution of mineral fertilizers to agricultural production is debatable but in any case the millions of field trials which have been carried out throughout the world demonstrate clearly their great influence on crop yields.

In an article in “The Observer”, New Delhi, April 17, 1997, Dr. Swaminathan, a leading Indian scientist, is reported as saying that *Fertilizer is the key to securing the food need of more than 1.3 billion Indians by the year 2025. No country has been able to increase agricultural productivity without expanding the use of chemical fertilizers. Working on a conservative population forecast of 1.3 billion by 2025, India would need 30 to 35 million tonnes of NPK from chemical fertilizers in addition to 10 million tonnes from organic and biofertilizer sources, to produce the minimum food grain need of 300 million tonnes. Scientists have found that there was growing evidence of the increasing deficiency of phosphate and potash in soils, aggravated by the disproportionate application of higher doses of N in relation to P and K. Sulphur has been identified as crucial for optimizing the yield from oilseeds, pulses, legumes and high-yielding cereals.*

N. E. Borlaug, a Nobel Prize winner, (1997), speaking of Africa, stated: *“My 53 years of experience in low-income developing countries tells me that small-scale farmers are loath to adopt such “low-input, low-output” technologies since they tend to perpetuate human drudgery and the risk of hunger. This certainly has been our experience in Sasakawa-Global 2000, where farmers have overwhelmingly told us they want access to yield- increasing, drudgery-reducing technology, and have proven that they are able and enthusiastically willing to modernize their production”.*

Several institutions, among them the FAO, IFPRI, UNDP, the US Department of Agriculture and the World Bank, have made projections concerning food security. They differ according to the assumptions made, but essentially they are in agreement that the world supply of food will have to keep growing, and growing rapidly. Agricultural investment, especially in research and advisory services, will be essential if the objective is to be achieved.

4. Economics

There is today a wide agreement that a necessary condition for economic growth in most developing countries is a productive agriculture - there are some exceptions, but they are few. This was not always the case. In the 1950s the emphasis in development policy was on urban industrial growth, with the agricultural sector being regarded as a source of inputs, mainly labour, for the manufacturing sector. It was only in the 1960s that the positive role of agriculture as an engine of development became accepted. Subsequent events in the 1970s and 1980s reinforced the need for more attention to be paid to agricultural development policies. But even today, some developing countries still do not attach sufficient importance to agricultural development. If agriculture is to be productive, it is evident that the crops should receive, from one source or another, the nutrients they require.

A June 1996 IFPRI study concerning Latin America confirmed how agricultural growth helps the whole economy. When agricultural producers' incomes rise, they spend money on non-agricultural items, creating jobs for others throughout the whole economy. The study found that for every US$ 1 increase in agricultural output in developing countries, the overall economy grows by US$ 2.3.

Apart from being good for the national economy, productive agriculture helps to alleviate rural poverty. Most of the world's poor are rural-based and, even when they are not engaged in their own agricultural activities, they rely on non-farm employment and income that depend directly or indirectly on agriculture. The rural poor make up more than 75% of the poor in many sub-Saharan and Asian countries.

Economic growth is strongly linked to poverty reduction. Poverty is itself a form of pollution and, in addition, the poor are often forced to overuse or misuse the natural resource base, in order to meet their basic needs.

Another, February 1994, IFPRI report described the results of a study in seven Asian countries, with widely diverse production environments and agrarian and policy structures, of the effect of technological change in favourable rice-growing areas, on the income of people in unfavourable ones - those by-passed by the new technology. The contributors found that when indirect effects of labour, land and product market adjustments are taken into account, differential adoption of high yielding varieties, HYVs, across environments does not significantly worsen income distribution. As HYV adoption increased the demand for labour in the favourable areas, more inter-regional migration from unfavorable areas took place, which mitigated potentially negative effects by equalizing regional wages. Shifts to alternative crops or non-farm employment in the unfavorable areas also contributed to equity.

A 1997 report by the Indian National Council of Applied Economic Research states that India could virtually eliminate urban poverty in a decade if it could sustain an annual economic growth averaging 6.4%. But the report also foresees growing disparities between Indian cities and the countryside where 74% of people live. Agricultural growth is stagnant. The report suggests that the urban 26% of the population will increase to 30% in 2007 but this does not take account of possible accelerated urbanization prompted by the rising income disparities.

5. Soils

As stated by A.E. Johnston (1997) soil fertility depends on complex, and often little understood, interactions between the biological, chemical and physical properties of soil. Understanding and quantifying interactions between the biological, chemical and physical properties of soil will become ever more important. He observes that it will be necessary in future to recognize more clearly that there is a distinction between the agricultural productivity and the fertility of a soil:

- Provided soil fertility is at a satisfactory level, within climatic constraints agricultural productivity may be controlled by annual inputs like N and chemicals to control weeds, pests and diseases.
- But soil fertility is frequently controlled by factors which are often difficult to manipulate in the short term, for example, chemical properties like soil acidity and plant nutrient status.

Wherever possible it will be necessary to define critical measures of soil fertility, and then ensure that soils are kept just above them. Below the critical value, loss of yield is a serious financial threat to the sustainability of any husbandry system. Maintaining soils much above the critical value is an unnecessary financial cost to the farmer and may have environmental implications.

5.1. Nutrient depletion

"The loss of soil fertility in many developing countries poses an immediate threat to food production and could result in a catastrophe no less serious than from other forms of environmental degradation". "Agricultural soils lose their fertility by plant nutrient depletion and, in some cases, plant nutrient exhaustion.....a real and immediate threat to food security and to the lives and livelihoods of millions of people. The loss of fertility reduces yields and affects water holding capacity, leading to greater vulnerability to drought." (FAO press release, April 1990).

A fertile and productive soil is the fundamental resource for the farmer and the entire ecosystem. The farmer's objective is to maintain the productivity of his soil. This implies the need for good stewardship on his part; that is, maintaining a good physical structure, organic matter content, good aeration, an adequate moisture content, proper pH and an optimal nutrient status. Management of such a system is complex. The sequence of crops grown, the number of livestock carried on the farm and the cultivation techniques employed by the farmer can either reduce or improve soil productivity.

As regards the plant nutrients, a crop's overall demand and the amount removed from the soil must be replaced, not necessarily annually, but certainly within the overall crop rotation, if soil fertility levels and long-term productivity (sustainability) are to be maintained.

The following paragraph is quoted from an IFPRI report on The World Food Situation published in October 1997.

"Past and current failures to replenish soil nutrients in many countries must be rectified through the balanced and efficient use of sources of 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. One of the largest environmental problems in Africa today is the gradual decline in the fertility of much of the soil".

The mining of nutrients is part of the cost of producing crops, often a hidden cost which is not passed on to the consumer. Under such circumstances, the use of public funds to help replace the mined nutrients may be justified, especially in situations where the farmer's financial situation is precarious.

5.2. The impact of fertilizers on soil structure

It is sometimes claimed that the use of mineral fertilizers has an adverse effect on soil structure. Evidence from very long-term experiments indicates that this is not the case. The aggregating action from enhanced root proliferation and greater amount of decaying residues from well fertilized crops makes soils more friable, easier to cultivate and more receptive to water. S.W. Buol and M.L. Stokes (1997) state *"Organic carbon contents that become lower under inadequate fertilization appear to recover when adequate fertilizer is applied. Adequate fertilization also contributes to greater biomass production tending to protect soil from erosion and providing greater quantities of residue critical to soil aggregation. We therefore conclude that long-term, high-input agriculture has a strong positive effect in improving agronomic properties of soils"*. Field plots at the Rothamsted Experimental Station in the United Kingdom, which have received chemical fertilizers since 1843, are more productive today than at any time in the recorded past. At the Askov experimental station in Denmark, after 90 years, the plots receiving NPK fertilizers had an 11% higher organic C content than the control plots. The increase in organic matter content induced by NPK applications resulted in a decrease in soil bulk density and a concomitant increase in total porosity (R.J. Haynes and R. Naidu (1998). They conclude that *"The long-term positive effect of continual application of fertilizer materials on soil organic matter content and soil physical conditions is an important, although often neglected, factor that needs to be considered when contemplating sustainability"*. In Japan (A. Suzuki, 1997) after 50 years of NPK fertilization there was no decrease over the years in the fertilized plots. The yield without fertilizer was about 40% of that of the fertilized plot.

5.3. Soil acidification

Most nitrogen fertilizers, especially ammonium sulphate and to a lesser extent ammonium nitrate, acidify soils, although some soils are naturally able to cope. The use of organic residues at normal levels of application may not avoid acidification but may slow the process.

The acidifying effects of nitrogen fertilizer can be corrected if lime is economically available and is applied. In temperate regions, lime, applied in quantities of tonnes per ha, but less frequently than fertilizers, provides optimum conditions for growth of many temperate crop species. Apart from neutralizing soil acidity, liming improves the availability of other nutrients such as phosphate, and lowers the toxicity of aluminium and manganese. In a long-term experiment in India, with the continuous application of fertilizers without lime, yields fell to zero. When the soil pH was kept near to the optimum, the system became sustainable.

In the humid tropics, the lime requirements are high and the effect may not last long due to leaching losses. However, increases in crop yields can sometimes be achieved with minimal applications of lime due to alleviation of aluminium toxicity and/or calcium deficiency and care must be taken to avoid over-liming (R.J. Haynes and R. Naidu, 1998). In many developing countries agricultural lime is not available at an economic cost. A possible solution lies in the development of cultivars which are tolerant of the direct and indirect effects of soil acidity.

5.4. Erosion

Soil erosion is a world-wide phenomenon, but is more serious in some regions than in others. In regions where a dry season alternates with a season with torrential rains soil erosion can be very severe. At the end of the dry season the soil is likely to have sparse vegetative cover, particularly if the land has been over-grazed by livestock. Under semi-arid conditions wind erosion and desertification are serious problems.

A fertile soil supporting a swiftly growing crop is much less erosion prone than a poor soil supporting a poor crop. The better developed the surface canopy the greater the protection against wind and water action. Because of their vigorous root systems and large residues, high yielding crops help to anchor the soil. The roots and residues returned to the soil enhance productivity by building up organic matter, by improving aeration and by increasing water infiltration rates. The residual effects of the greater organic matter production are significant also in improving soil aggregation.

Land use management appropriate to the topography and rainfall, together with the appropriate use of fertilizers, can make an important contribution to soil conservation.

Reduced tillage cultivation practices significantly reduce erosion; the proportion of crop land subject to no-till techniques is expanding rapidly in the USA and certain other countries, for example in Brazil.

6. Toxic substances

Phosphate fertilizers often contain small amounts of elements which occur naturally in phosphate rock and are carried through, in the manufacturing process, to the finished product. When the final product is a relatively high-value material destined for use, for example, in the food industry the potentially harmful elements are removed, but to date economic processes for removing these elements economically in fertilizer production have not been found. Among these elements, most attention has been paid to cadmium (Cd).

There is evidence that Cd is slowly building up in some soils. This is of concern because Cd is not essential to plants or animals, and at high levels can be toxic. Sources include atmospheric deposition from industrial processes, sewage sludges, animal manures and phosphate fertilizers. In many European countries about 50% of total Cd input to agricultural soils is from airborne sources. Sewage sludges contain amounts of Cd which can vary from a few p.p.m. to several thousand p.p.m. The use in the manufacture of phosphate fertilizers of phosphate rock with a low cadmium content is one solution, but the total supply is limited. This places the emphasis on developing effective and viable cadmium removal processes and research with this objective continues.

Ultimately the solution could be a combination of the removal of Cd in the manufacturing process and farm management strategies which minimize its potential entrance into the food chain. The uptake of Cd by plants can in fact be affected by many factors, such as soil pH, moisture content, variety etc., which can be controlled by the farmer.

There is no immediate urgency because, apart from a few sites heavily polluted by industry, soil cadmium levels are generally well below critical levels. However, the existence of a medium and long-term problem is recognized by the fertilizer industry and studies and research on the subject continue.

7. Water

There is concern that fertilizers are polluting both surface waters and water in aquifers, although the direct impact of the application of mineral fertilizers on the nitrate content of waters is poorly defined.

According to Union des Industries de la Fertilisation (UNIFA), 1997, in France, it is estimated that nitrogen fertilizers account for 25% of total mineral nitrogen introduced annually into the eco-system, or 2.3 Mt N out of a total of 9.4 Mt N. Other major inputs are from nitrogen fixed by leguminous plant (3 Mt N) and animal wastes (2 Mt N). In a major catchment area in France, 42% of the nitrogen in the water was of agricultural origin (arable and livestock), 49% domestic and 9% industrial. Labeled ^{15}N experiments indicate that not more than 5% of fertilizer nitrogen is lost to water during the growing season, two thirds of it due to incorrect fertilization practices. In general the extent of losses is not linked directly to recent fertilizer applications. Of the agricultural losses 50% was from soils which were left bare in winter and 33% due to poor cropping practices i.e. losses which could be avoided.

7.1. Drinking water

In the mid-1980s the World Health Organization (WHO) recommended a limit of 50 mg of nitrate, NO_3, per litre of drinking water. They reviewed the recommendation in April 1997 and concluded that, on the basis of the latest scientific evidence, the value of 50 mg per litre should be maintained.

The European Union (EU) issued a drinking water directive in 1975. In 1980 another directive set a level of 50 mg per litre. Then, in December 1991, the EU adopted a directive, known as the Nitrates Directive, concerning the protection of waters against pollution caused by nitrates from agricultural sources. This directive recognized that, whilst the use of nitrogen-containing fertilizers and manure is necessary for EU agriculture, any over-use of fertilizers and manure constitutes an environmental risk. It emphasizes that common action is needed to control the problem arising from intensive livestock production, and that agricultural policy must take greater account of environmental protection.

The objectives of the directive are to ensure that the nitrate concentration in freshwater and groundwater supplies does not exceed the limit of 50 mg NO_3 per litre and to control the incidence of eutrophication. Having set the overall targets, the directive requires individual Member States, within prescribed limits, to draw up their own plans for meeting them. These plans involve the preparation of a voluntary Code of Good Agricultural Practice, the designation of zones vulnerable to water pollution from nitrogen compounds and the implementation of action programmes designed to prevent pollution within those zones. The measures include a maximum limit for the addition of livestock manure – the main culprit - equivalent to 170 kg nitrogen (N) per hectare. In addition, the periods in which it is acceptable to apply animal manure are defined.

The agricultural techniques for keeping nitrate out of water supplies are known. The European Fertilizer Manufacturers' Association (EFMA), for example, has explained these techniques in a code of best agricultural practice (EFMA, 1996).

In general, in developed countries, where mineral nitrogen fertilizer is a major source of water pollution it is usually in areas of vegetable production or irrigated sandy soil, or where the optimum rates are exceeded. A distinction must be made between correct nitrogen fertilization and excessive animal excrement application.

There is generally little danger of the nitrate pollution of ground water due to the application of fertilizer on rain-fed crops in developing countries, both because the application rates tend to be well below the optimum. In irrigated agriculture, water management is an important issue.

Section 12.1.1. “Nitrates” of this publication concerns the human health issue of nitrates.

7.2. Surface waters

The over-enrichment of surface waters leading to an excessive multiplication of algae and other undesirable aquatic plant species, with various undesirable consequences, is a phenomenon known as eutrophication. Whereas phosphate tends to be the limiting nutrient in inland waters, nitrogen tends to be the limiting nutrient in coastal waters.

7.2.1. Coastal waters

In Europe large areas of the North Sea coastlines and areas of the Mediterranean have suffered from eutrophication due to nitrates. In the USA, nitrates and phosphates are suspected of causing *Hypoxia*, or the “Dead Zone” in the Gulf of Mexico. There is a great deal of controversy as to the cause, and even if these nutrients prove to be the cause, they may originate from several different sources apart from mineral fertilizers. Nutrient-enriched water, especially run-off from agriculture, is also incriminated in the *Pfiesteria* problem that killed a large number of fish in Chekaspeake Bay, USA, in the summer of 1997. It is highly unlikely that mineral fertilizers are primarily responsible for either of these problems, but the U.S. fertilizer industry is co-operating fully in the investigations.

7.2.2. Inland waters

Under temperate conditions, in inland fresh water, P is usually the limiting nutrient and very low concentrations can cause problems of eutrophication. Surface water can be enriched with P from both point (e.g. sewage treatment works) and diffuse (e.g. agricultural land) sources. As the amount of P from point sources has declined in recent years, the percentage contribution from diffuse sources has increased. Although it has been generally accepted that most soils fix P strongly, only very small amounts of P have to be lost from soil to maintain the concentration of P in drainage at levels likely to cause environmental problems.

Phosphate in the soil is rather immobile and the loss of water-soluble phosphate through leaching is usually very small (less than 1 kg of P_2O_5 per hectare per year). Ignoring crop removal, the two primary pathways of loss of phosphorus from the soil are by erosion (wind and water) and in run-off. Under European conditions, the excessive surface applications of animal manures can result in significant losses in particulate matter in run-off. Areas where intensive animal husbandry is practiced may experience the addition of excessive amounts of phosphorus to the soil, usually in the form of heavy applications of animal waste eg. slurry or farmyard manure. Under these conditions, soils can have such a high content of phosphorus that losses may increase.

In tropical lakes, there is evidence that nitrogen can be the limiting nutrient. Phosphate concentrations in the water are often higher than in temperate regions while inputs of N from surrounding land may be low.

Surface runoff (including soil erosion) from cropland, pasture and forest, can contribute to phosphate loading of surface waters. Best management practices are highly effective in eliminating this possibility and, at the same time, allow for the most efficient use of crop fertilization.

7.3. Potash

Unlike nitrogen and phosphate, potash has no known deleterious effect on the quality of natural waters (J.K. Syers, 1998).

8. Air

Nitrogen can be lost from agricultural systems in three forms which may cause pollution; nitrate loss by leaching, ammonia volatilization and nitrous oxide loss during denitrification or nitrification. Ammonia loss to the atmosphere and its subsequent deposition contributes to the eutrophication of natural habitats and marine waters and to the acidification of soils and lakes as the NH_4 is converted to NO_3. Losses by denitrification are harmless if the end product is nitrogen gas but if the resulting gas is nitrous oxide there is a contribution to the greenhouse effect and to depletion of ozone in the upper atmosphere.

8.1. Ammonia

H. Kirchmann (1998) observed that ammonia deposition from the atmosphere may enrich terrestrial and aquatic ecosystems. On average in West Europe 92% of all ammonia originates from agriculture. About 30% of the nitrogen excreted by farm animals is released to the atmosphere from animal houses, during storage, grazing and application of animal wastes to the soil. Ammonia emissions from growing arable crops are low, but emissions can be higher from decomposing crops. Composting results in high ammonia losses.

Deposition of ammonia takes place over areas where lower amounts would have been supplied. This deposition together with that from nitrogen oxides decreases biodiversity, but it can increase carbon storage in sediments and forest soils. Near very large animal farms, local toxic effects damaging the surrounding vegetation can occur.

Ammonia deposition contributes to acidification of soils as ammonia is nitrified to nitrate and then nitrate is lost by leaching.

Ammonia can also react in the atmosphere with sulphur oxides to form ammonium sulphate, which precipitates into the soil with rainfall and causes acidification.

Although most emissions of ammonia are from manure or natural sources, experiments demonstrate that nitrogen losses to the atmosphere in the form of ammonia following the application of urea can amount to 20% or more, under temperate conditions. Losses occur when the urea is not incorporated into the soil immediately after spreading and they are particularly high on calcareous soils. The expanding practice of reduced tillage cultivation is increasingly the surface application of urea. Losses are even higher, up to 40% or more, under tropical conditions, on flooded rice and on perennial crops to which the urea is applied on the surface, such as bananas, sugar cane, oil palm and rubber.

8.2. Greenhouse gases

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the three most important greenhouse gases. They absorb solar radiation rather than allowing the heat to be radiated away from the earth. Their impact as greenhouse gases, or global warming potential (GWP), is a function of two factors, their “radiative forcing” and on their lifetime in the air. Taking the GWP of CO_2 as 1, that of CH_4 is 21 and that of N_20 is 310.

8.2.1. Carbon dioxide

Fixation of carbon dioxide by photosynthesis is the source of organic carbon in crops and eventually in soils. Crop production practices that enhance photosynthetic activity improve the retention of carbon. Decomposition of organic matter releases carbon dioxide back to the atmosphere. Good fertilization and tillage management practices improve the net gain of carbon to the soil.

Recent estimates indicate that agricultural and forested land in the Northern Hemisphere is now a net sink for carbon dioxide from the soil/plant complex due to increased vegetative growth. According to E. Solberg (1998), for every pound of nitrogen applied as fertilizer, 10 to 12 pounds of carbon can be sequestered. The rapidly increasing use of reduced tillage systems is helping to rebuild soil organic matter, hence increasing the quantity of carbon stored.

8.2.2. Nitrous oxide

Nitrous oxide has a greenhouse effect and is considered to be detrimental to the ozone layer. According to experts of the Intergovernmental Panel on Climate Change (IPCC), nitrous oxide is responsible for 7.5% of the calculated greenhouse effect caused by human activity. Its concentration in the atmosphere is increasing at a rate of about 0.2% per annum. Soils are the major global source of N_2O accounting for some 65% of all emissions; they are the result of microbial processes. Nitrogen fertilizers can be a direct and indirect source of N_2O emissions; IPCC currently assume an N_2O emission factor of 1.25% of fertilizer N applied, but with a nine-fold range, from 0.25% to 2.25%. In general, fertilizer management strategies that increase the efficiency of N uptake by crops are likely to reduce emission of N_2O to the atmosphere. For further information, refer to O.C. Bockman and H.-W. Olfs (1998) and K.A. Smith et al. (1997).

8.2.3. Methane (CH_4)

Methane production mainly stems from wetlands, paddy fields, gastric fermentation within ruminant animals, animal wastes, domestic sewage and abiotic sources such as coal mining and natural gases etc. The direct impact of chemical fertilizers on methane emission is not clear.

In the USA it is estimated that agricultural sources account for 29% of US methane emissions. Of the agricultural emissions ruminant animals account for 62%, animal waste for 32% and rice paddies for 5%. There are indications that cultivation and N fertilization decreases the rate at which CH_4 is taken up from the atmosphere by soils, thus contributing towards atmospheric methane levels, but the amounts involved are small relative to total sources. (W. Griffith and T. Bruulsema, 1997).

A. Suzuki (1997) reports that rice paddy fields in Japan are thought to account for about 10% to 30% of total methane emissions from all sources. In rice paddies methane is formed by the anaerobic decomposition of organic matter. The addition of readily decomposable organic matter significantly increases methane emissions.

9. Nutrient losses and efficiency

In view of the large quantities involved, inefficiencies in fertilizer use represent a substantial economic loss. For example, given that about 80 Mt of N were used in world agriculture 1996, a 20% loss with a wholesale price of US$ 0.66 per kg of N in urea, amounts to US$ 10.6 billion. Excessive losses of nitrogen and phosphate to waters and of nitrogen to the atmosphere also present an environmental risk.

Plants acquire most of their nutrients either from soil reserves or from recently added fertilizers or organic manures. Assessing whether added nutrients are used efficiently is usually done by the difference method.

$$\text{\% efficiency (recovery)} = \frac{\text{Au in crop given Aa} - \text{Au in crop without A}}{\text{A}} \times 100$$

where A is the nutrient tested at amount Aa, and Au is the amount of A in the crop grown with and without A. Calculated in this way the recovery of added nutrients is very dependent on the yield of the crop receiving the nutrient being tested, and the amount of nutrient which is supplied by the soil. Different time scales can be used. Usually only one crop or year is considered but, for soils in which reserves of plant available nutrients can be accumulated, it is appropriate to consider a longer time span.

A. Finck (1992) considered that the proportions of fertilizer nutrients taken up by the crop during the season of application are as follows:

- Nitrogen: 50-70%
- Phosphate: 15%
- Potash: 50-60%

Data from Rothamsted Experimental Station in the UK for phosphorus, show that from 1843 to until the 1970s, the overall P offtake was about a third of that applied, similar to Finck's data. But with today's yield of 8.5 t/ha grain, the P offtake in grain plus straw is almost equal to the annual application, of 35 kg P/ha, although not necessarily from the P applied for that particular crop. Similarly the increased yield of winter wheat now removes in grain plus straw most of the K applied each year (90 kg K/ha).

9.1. Nitrogen

When assessing the efficiency of nitrogen, it is important to take account of the fact that the plant is, in fact, in competition with the soil microbial population. This is especially so in soils in which organic matter is accumulating.

Pilbeam (1996) collated data from experiments in which ^{15}N labeled fertilizer, with N in different forms, was applied at different growth stages to rain-fed crops of wheat grown in different locations worldwide. The proportions of nitrogen taken up by the crop and soil respectively varied widely in response to differences in rainfall and evaporation between the locations but the proportion of applied labeled N that was unaccounted for, and presumably lost from the crop-soil system, was largely independent of variations in climate. The unexplained loss of fertilizer N ranged from 10% to 30%, average 20%.

A.E. Johnston (1997) reported that ^{15}N experiments at the Rothamsted Experimental Station in the U.K. showed that, on average, about 20% of the applied N had been incorporated into soil organic matter between application and harvest.

These two factors, the unavoidable and partly unexplained N loss averaging 20% and the average of 20% incorporated into the soil, correspond to Finck's 50 to 70% estimate of plant uptake. The nitrogen incorporated into the soil as organic matter may subsequently be mineralized and become available to subsequent crops. And because it is not easy to predict both the amount and time at which this organic nitrogen is mineralized it is difficult to give accurate recommendations for fertilizer nitrogen applications.

Although 50% to 70% of the applied nitrogen can be taken up under the controlled conditions of experimental stations, in practice, losses can be much greater.

R. S. Paroda (1997) stated, in relation to India, that "*The nitrogen use efficiency varies from 20 to 25% in rice, 21 to 45% in maize, 45 to 50% in wheat. A 1% increase in the recovery rate of N fertilizer would save 98 Kt N, equivalent to 1 Mt food-grains. In the case of phosphate, recovery varies from 15% to 20%*". In an earlier paper, R.S. Paroda et al. (1994) observed that in the rice-wheat systems of Asia, nitrogen fertilizer efficiency is estimated at around 30 to 40%. For micronutrients, such as zinc, the efficiency seldom exceeds 10 to 15%.

The following text is extracted from a paper by Peoples et al. (1995).

"*Unfortunately, fertilizer sources are not utilized efficiently in agricultural systems, and plant uptake of fertilizer N seldom exceeds 50% of the N applied. One of the principal reasons for the poor efficiency in fertilizer use is that a proportion of the N applied (up to 89%) is lost from the plant-soil system. Fertilizer N can be lost by leaching, erosion and run-off, or by gaseous emissions. The relative importance of these processes can vary widely, depending on the agricultural system and the environment. Similarly the relative importance of NH_3 volatilization and denitrification varies considerably and depends on the agro-ecosystem, form of fertilizer N used, crop management imposed and the prevailing environmental conditions. It is puzzling that farmers in so many countries tolerate the poor efficiencies of fertilizer use. They persist with poor agronomy when simple management practices are available which could increase the efficiency of N uptake and decrease costs of production. Special problems arise with crops such as rice, cotton and sugar cane which receive large applications of N but which also lose large amounts of N by denitrification and NH_3 volatilization. When the economic situation is good, farmers are unconcerned about applying excess amounts of N, but the environmental consequences of this wasteful practice certainly need to be considered. ...Many approaches are now available to control the losses of fertilizer N by NH_3 volatilization and denitrification*".

In work in China (A. Dobermann, 1998), in 25 on-farm experiments, the average plant recovery of N by an early rice crop averaged 29% (range 10% to 65%), compared with 41% in a experimental station trial. In the case of farmers' practice 5 kg grain per kg of N applied was obtained compared with 24 kg on the experimental station. On a late rice crop, recovery averaged 5%, range 0% to 12%. The author estimates that only 60% of the potential yield is achieved in intensive rice-growing areas of Asia, with very high N losses to the environment.

In trials on rice in Vietnam (A. Dobermann, 1998), average recovery efficiency of applied N was 40% in farmers' practice, but with a yield of only 11 kg grain per kg N applied. At another site, with improved agricultural practices a recovery of 69% was obtained by farmers, and 30 kg grain per kg N.

Much can be achieved by improving management practices. Matson et al. (1998), working on wheat in an intensive agricultural region of Mexico, found that an improved management system reduced gaseous loss of N from about 14 kg N/ha to virtually zero.

A greater plant uptake can also be achieved with new varieties. A. Suzuki (1997) reported that a high yielding variety of rice in Japan took up about 160 kg N per ha whereas a commonly grown variety took up 130 kg/ha.

9.2. Phosphate and potash

Until a few years ago, it was believed that phosphate (and potash) “fixed” by the soil went over into plant-unavailable, inert and hence useless forms. There has, however, been a change of perception in recent years. Experiments have shown that in many soils reserves of plant available P and K can be built up over time. Soils enriched with these reserves frequently gave larger yields than soils without the reserves. Hence the plant-uptake figure of 15% for P underestimates the long-term efficiency of phosphate fertilizers. Phosphate (and potash) residues accumulated in the soil are not necessarily lost - but this is not a reason for accumulating these residues unnecessarily. There are critical values of phosphate and potash below which yield decreases appreciably and which represent a financial loss to the farmer. To accumulate P and K in the soil above these critical levels is an unnecessary cost for the farmer. It may also pose an environmental risk, in that soil lost by water or wind erosion to streams, rivers and lakes takes its nutrient load with it (A.E. Johnston, 1997). Further work is required to establish these critical soil levels under different conditions. Work to improve the plant uptake of applied P and K is also required.

Phosphate has both direct and indirect effects. The increased availability of phosphate has a positive effect on the quantity and quality of agricultural outputs. Through indirect interaction effects, phosphate increases the response of agricultural production to the other inputs such as nitrogen and potassium and has positive effects on biological nitrogen fixation, soil organic matter maintenance, water-holding capacity, soil erosion control and other soil physical and chemical properties. All of these positive effects result in increased agricultural output, sustained productivity and land conservation (C.A. Baanante, 1998).

9.3. Products

How can these high losses of nitrogen be reduced? In fact, improvements in fertilizer use efficiency can be detected in most agriculturally advanced regions, but this can be attributed to improvements in cultivation practices, techniques of fertilizer application and crop varieties. Apart from some developments in coated, controlled release fertilizers and nitrification inhibitors, there has been little significant change in the fundamental nature of the main fertilizer products for many years, or even decades. There is little incentive to invest in the research and development of a bulky, low-priced commodity which offers little scope for product differentiation.

9.3.1. Slow release fertilizers

Controlled release nitrogen fertilizers have agronomic advantages, especially in tropical regions, and in regions with light-textured soils and under heavy rainfall or irrigation, where N losses are particularly large. However, to date the cost of slow-release fertilizers has limited their use to high value crops such as vegetables.

The use of controlled release nitrogen fertilizers on field crops is most advanced in Japan, on rice, whose production is heavily subsidized. The amount of fertilizer required by rice is commonly applied in 3 to 4 applications. This is labour intensive and in order to reduce the number of applications, coated slow-release fertilizer have been studied. Experimental results so far have indicated that a single application of the whole amount of coated fertilizers in a basal application gives yields comparable to those with traditional split applications. Also the efficiency of nitrogen use could be improved by 10% to 20% due mostly to an increase of about 16% in the plant uptake of N.

9.3.2. Nitrification and urease inhibitors

Environmental restrictions in certain developed countries may encourage more farmers to use nitrogen or urease inhibitors in association with nitrogen fertilizers in areas where it is essential to reduce losses for environmental reasons. The application of urea (or a urea/ammonium nitrate solution, UAN) amended with a urease inhibitor would generally permit a substantial reduction in nitrogen losses to the atmosphere, and consequently also in the application rates, without affecting growth and yield of fertilized crops.

The future, and in particular the wider use of slow or controlled release fertilizers, and nitrification and urease inhibitors primarily depends on the development of new, effective, low-price and non-toxic products. Even if promising new products were developed, due to lengthy, time-consuming tests and data collection for registration purposes, the introduction to the market would take several years. It should also be taken into account that giving advice to farmers on how to use them correctly would be very expensive.

The whole question of controlled release fertilizers, nitrification and urease inhibitors, is dealt with by in detail by M.E. Trenkel (1998).

9.3.3. Nutrient absorption enhancers

Increasing the absorption of applied nutrients by the plants, as opposed to the soil, is a means of increasing fertilizer use efficiency. J.L. Anders and L.S. Murphy (1997) presented work with a polymer which shows improved nutrient uptake and nutrient use efficiency.

9.3.4. Bio-fertilizers; microbial inoculants

Microbial seed inoculants, commonly but wrongly called bio-fertilizers, are able to enhance biological nitrogen fixation or to solubilize soil phosphate. The inocultants are claimed to be cost effective, eco-friendly and renewable, and generally capable of supplementing chemical fertilizers in sustainable agricultural systems.

It has long been known that the inoculation of efficient strains of the symbiotic *Rhizobium* can be beneficial for leguminous pulses and oilseeds. Free-living organisms such as *Azobacter* and *Azospirillum* have proved effective for rice and certain other crops. The problem with inoculants is that establishment and therefore effectiveness depend on the natural conditions and on the skill of the user. As regards the product itself, the inoculant is a living material and there are problems due to the need to select the most effective strains, the difficulty of quality control, the short shelf-life, the need to avoid high temperatures in storage etc.

As regards phosphate, several phosphate-solubilizing bacteria are known to mobilize significant quantities of soil phosphate that would otherwise not be available to the plant, but their effectiveness is variable and not predictable. Vesicular-arbuscular mycorrhizae have favourable effects on P uptake but much more research and development is required before reliable commercial products can be made available. At present it is difficult to produce mycorrhizae in bulk.

The Food and Fertilizer Technology Center for the Asia and Pacific Region (FFTC, 1997) report that, while there is an increasing interest in Asia in the use of N-fixing and P-solubilizing bacteria, the technology of producing and using them is still at an early stage. While some are very effective, farmers often find themselves paying large sums for useless products. There is a very large number of different microorganisms in microbial products and they are often not identified, whereas some are crop-specific. They tend to be heavily promoted and there is a great need for standards and for simple and accurate ways of measuring their effectiveness.

In general, microbial inoculants have received only limited acceptance by farmers in developing countries. They show considerable promise but more development is required. In general, it seems likely that, in due course, they will become significant supplements to mineral fertilizers but they cannot replace them.

A considerable amount of work has been done on microbial inoculants in India. In 1996 there were 62 manufacturing units in the country. The Fertiliser Association of India has produced a booklet on the subject (FAI, 1994).

9.4. The efficient use of fertilizers

Efficient fertilization is important from both an economic and an environmental point of view. It is synonymous with minimizing nutrient losses to the environment, while optimizing crop yields. Excess nitrogen not taken up by the crop is likely to be lost to the environment. The quantities and relative proportions of the different nutrients required by particular crop and soil conditions must be respected. The challenge is to maintain the fertility of soils despite the increasing demands placed on them.

Fertilizer use efficiency has in fact been improving in the developed countries. In the USA, for example, between 1985 and 1995, corn production per kg of nitrogen applied increased from 18 kg in 1985 to 22 kg in 1995. The situation is much the same with phosphate and potash. There has been a similar improvement in West Europe, where agricultural production has continued to increase despite reduced fertilizer use.

9.5. Fertigation

A technique which enables growers to maximize the use of water resources and to increase the efficiency of fertilizer use is "fertigation". This technique is particularly appropriate for high value crops under arid and semi-arid conditions; it is widely used in Israel. It involves the addition of soluble fertilizers into irrigation systems, preferably using a "drip system" which allows uniform water distribution and feeding of the crop. The fertilizer can be applied to the crop whenever it is needed. The initial investment cost may be expensive, but all irrigation systems are expensive. Maintenance of the system and its management requires skilled labour.

9.6. Balanced fertilization

If any plant nutrient, whether a major nutrient or a micro-nutrient, is deficient crop growth is likely to be affected. One definition of balanced fertilization is "the nutrient mix which gives the optimum economic return". This may be at high levels in intensive agriculture, or at comparatively low levels in less favourable circumstances. In either case balanced fertilization is necessary for use efficiency.

The application of nitrogen fertilizers tends to be preferred by farmers, because of their relatively low cost per unit of nutrient, their widespread availability, and the quick and evident response of the plant. However, the increased yields deplete the soils of the other plant nutrients removed by the harvested crops, unless they are replenished.

Research at IRRI in the Philippines has shown that while the application of an adequate quantity of N increased the yield of rice paddy 2.9 times, it also resulted in the removal of 2.6 times more P, 3.7 times more K and 4.6 times more S from the soil, compared to the amounts removed from unfertilized soil. In due course, these nutrients have to be replaced if the yields are not to suffer. The same applies to micronutrients.

In a 1995 FAO document "*Rice and the environment: production impact, economic costs and policy implications*" it is stated that incorrect fertilizer use in much of Asia, unbalanced in favour of nitrogen, results in lodging, greater weed competition and pest attacks, with a financial loss varying from 4% to 30% of the rice price.

"Fertilizer use has been increasing rapidly in Pakistan over many years but there is a stagnation of crop production. This seems to be due largely to the incorrect use of fertilizers. Farmers have been applying high amounts of nitrogen, but only small quantities of phosphate. Other fertilizers, such as potash and micronutrients are hardly used at all. Organic sources are not being properly integrated with mineral fertilizers. Under such conditions, the soil is depleted and it takes more nitrogen every season to obtain the same crop". (Fertilizer Recommendations in Pakistan, NFDC, 1997, page 1.)

9.7. Site specific fertilizer application

The need for rational and sustainable land use, especially in regions subject to severe population pressures, emphasizes the need for effective land use planning. The classification of land types according to their agricultural suitability, together with the implementation of soil conservation measures, was used with great success to combat the erosion and desertification problems encountered in US agriculture in the 1930s.

Fertilizer recommendations should take into consideration specific agro-climatic and environmental conditions. General recommendations need to be adjusted to the conditions of the particular field. They depend on factors such as soil characteristics, cultivation practices, quality and quantity of irrigation water, ground water table, crop rotations and the managerial capacity of the farmer. The expected yield level of a crop is an important consideration.

The rapid progress in information technology during the past decade, including Geographic Information Systems (GIS) and computerized mapping, offers the possibility of agro-ecological zoning which can help in a preliminary selection of crops and technologies, including appropriate fertilizer use, suited to the local conditions and the problems encountered.

In highly developed systems, precision farming may use satellite communication and detailed field and crop information to improve farm operations and nutrient efficiency by means of the site-specific application of fertilizers. Soil analysis and crop deficiency diagnosis to facilitate the fine-tuning of fertilizer rates to actual crop requirements are of fundamental importance to precision agriculture.

Precision agriculture does not, of course, necessarily require sophisticated machinery and satellite-positioning systems. Farmers in developing countries could well improve the precision of their plant nutrient programmes given soil testing facilities and sound advice.

10. Integrated systems

R.N. Prasad. (1997) stated *"The ultimate goals or the ends of sustainable agriculture are to develop farming systems that are productive and profitable, conserve the natural resource base, protect the environment and enhance health and safety in the long run. Traditional agricultural systems that met the test of sustainability in the past have not been able to respond adequately to today's growth in demand for agricultural commodities required by the current population pressures of humankind and animals and rapidly declining resources of good quality arable land and water resources.*

The basic principles of soil management for sustainable agricultural systems are:

- *Replenish nutrients removed*
- *Maintain the physical condition*
- *No build-up of weeds, pests and diseases*
- *No increase in soil acidity or toxic elements*
- *Soil erosion must be controlled to be equal or less than the rate of soil genesis".*

10.1. Integrated farming

"Integrated farming" or in French "Agriculture raisonnée" is the combination of farming practices - including the use of rotations, cultivation, choice of variety and skillful, precise use of fertilizers and crop protection products - with measures to preserve and protect the environment. The best combination must be specific to each farm.

The concept is based on the German model (FIP) founded in 1987. In the UK LEAF (Linking Environment and Farming) has support from the government, farming groups, research organizations, the fertilizer industry, environmental campaign groups and consumer organizations. In France, FARRE, the "Forum de l'agriculture raisonnée respectueuse de l'environnement" is gaining widespread support.

"Integrated farming" takes systematic and simultaneous account of the environmental aspects, the quality of the produce and the profitability of the farm. Its aim is to develop an agriculture which is sustainable but which corresponds to the farmers' needs and to society's expectations. Soil and water resources and biodiversity are respected. Fertilization and crop protection techniques which minimize adverse environmental impacts are adopted. Animal health and well-being, management of effluents and waste, optimal use of water resources and erosion control are all taken into account. "Alternative farming" has ideological undertones whereas "integrated farming" aims to make optimum use of the best known techniques.

A. Leake (1999), of the CWS Farms Group in the UK, has stated *"Integrated farming is a recent development but is already showing promise in its ability to deliver high yielding crops, cost effectively with reduced environmental impact. Such a system offers a real alternative for European agriculture compared to conventional high input systems and organic low output farming".*

10.2. Land planning

There are examples in certain regions of the EU and elsewhere, particularly in water catchment areas, of successful co-operation between farmers, water authorities and agricultural advisory services which have enabled local environmental targets to be achieved. "Landcare" in Australia is an example of a successful land management programme. There are comparable programmes in certain other countries, such as Brazil, India, South Africa....

10.3. Ferti-Mieux

In France, in 1980, the French government established COMIFER, the "Comité français d'étude et de développement de la fertilisation raisonnée", whose objective is to promote rational fertilization "fertilisation raisonnée", making use of all scientific, technical and practical means. It is composed of representatives of public authorities and educational establishments, farmers' organizations, fertilizer producers and distributors.

"Ferti-Mieux" defines the steps to be taken in order to obtain, in a given catchment area, a progressive change in agricultural practices which would minimize the risk of polluting water. Participation is voluntary. It is based on a consensus, on a national basis, between the Ministry of Agriculture, the farmers' associations, the fertilizer associations, other Ministries etc., and at the local level, between farmers, advisors, consumers, water agencies etc.

An approved Ferti-Mieux operation, which respects the guidelines, is recognized by a label, which is attributed, for one or two years, by three different national bodies. The label provides a guarantee, for farmers, advisors, financial bodies and the general public.

10.4. Integrated plant nutrition systems, IPNS

In 1996 IFA published a document prepared by R. Dudal entitled "Plant Nutrients for Food Security", drawing attention to the importance of the effective management of plant nutrients as a major component of agricultural development. A substantial part of the document is concerned with *integrated plant nutrition systems* (IPNS) and related subjects. He defined Integrated Plant Nutrition as "*an approach which adapts plant nutrition to a specific farming system and particular yield targets, the physical resource base, the available plant nutrient sources and the socio-economic background*".

The sources of plant nutrients may be mineral fertilizers and/or biological nitrogen fixation and/ or organic materials, depending on the circumstances.

Recommendations of an FAO-IFFCO (Indian Farmers Fertiliser Cooperative) International Seminar on IPNS for Sustainable Development held in New Delhi, India, in November 1997 were as follows:

- The development of IPNS requires an improved service to the farmers, in the form of technical advice, inputs, credit, marketing facilities, public investment in agriculture.

IPNS should:

- address both increased productivity and increased profitability for farmers, with special attention paid to the alleviation of poverty in rural areas,
- integrate the maintenance of natural resources and rehabilitation of these resources where needed and the enhancement of productivity in agriculture,
- be system-oriented and should in particular take account of the interactions between plant nutrient supply and water supply, between plant nutrient supply and the control of pests and diseases,
- improve the availability of energy for the rural population, in order to save fuel wood and organic materials used as an energy source,
- be science based, associating agronomy, ecology and social science,
- use a "Farming Systems" approach, not limited only to cropping systems.

10.5. Leguminous plants as a source of N

Leguminous crops provide a substantial input of nitrogen into the eco-system. It has been estimated that biological nitrogen fixation supplies about 30 to 40 Mt nitrogen per year, which compares with about 80 Mt from fertilizer nitrogen. The contribution of leguminous plants to crop nutrition has long been known and made use of in traditional systems.

Leguminous crops have a high requirement of phosphorus and potassium and this has to be supplied. The micro-organisms, living in symbiosis, receive their energy from the plant in return for the nitrogen they produce. They are not efficient converters and the energy used in the natural fixation process is at the expense of the yield of the crop i.e. yields of leguminous crops tend to be low.

The possibility of using leguminous crops as a source of nitrogen is of particular interest to small-scale farmers who cannot afford to purchase nitrogen fertilizers. They are not, however, cost-free. If the production of the leguminous crop is not otherwise economic, they occupy land which might be put to better use. M.E. Summer (1998) draws attention to trials in Africa in which a rotation comprising two or three years of *Sesbania* fallow followed by maize gave a spectacular increase in maize production compared with unfertilized, continuous maize. However, he points out that it is still necessary to apply phosphate. Furthermore, the maize production was less than half of what could be achieved with a modest nitrogen fertilizer input.

Nor is nitrogen derived from leguminous crops more environmentally friendly than that provided by mineral fertilizers; in fact it is likely to be less friendly. The amount, rate and timing of nutrient release is difficult to control. In trials on grass/clover leys in the UK (Johnston et al. 1994), following the ploughing of the leys, winter wheat was grown and soils were sampled during the winter and spring. It was calculated that between 110 and 250 kg N per ha were leached as the ley length increased from 1 to 6 years. In the average, through drainage on this soil, the amount of N raised the nitrate concentration in the drainage from just below 200 mg/l to 400 mg/l, eight times the EU limit for nitrate in drinking water.

Green manures, particularly of nitrogen-fixing leguminous plants, are an important source of nitrogen. However, they can be unattractive from the farmer's point of view if they do not produce a salable or comestible product. Farmers with only a small area of land can scarcely afford to use part of it unproductively. *Green manures* are labor intensive. They provide significant amounts of nitrogen but require the application of phosphate and other nutrients. They are no more environmentally friendly than mineral fertilizers; for example, there is evidence that nitrous oxide is emitted from fields after legumes in amounts similar to those from fertilized crops. The release of the nitrogen fixed by leguminous crops is difficult to control.

Azolla, a floating aquatic fern associated with nitrogen-fixing blue-green algae is used as a source of nitrogen for flooded rice (FAI, 1994). Used as a green manure the optimum application amounts to several tonnes per hectare. The fern requires a considerable quantity of water and of phosphate and it cannot withstand high temperatures. Green manures, such as *Sesbania* have long been used in China (see the report of a study tour in China, FAO, 1977) but since the date of that tour the use of nitrogen fertilizers there has increased from 8 to 23 Mt N.

11. Nutrient accounting

Using comparisons of nutrient inputs and outputs as a yardstick for environmental correctness of fertilizing practices in scientific publications and studies started during the 1980s. Different types of nutrient balances came into use. The most common is a comparison of nutrient inputs and outputs at farm gate level (the alternative "soil surface balance" is more complicated). The account examines the relationship between applied nutrients and nutrients removal in the harvested crop. It considers all nutrients, whether of mineral or organic origin, which may be applied. The system ideally should also consider changes in soil nutrient levels and, in some cases, admissible losses.

Nutrient accounting is being developed by the OECD as one of the environmental indicators. These are national indicators K. Parris and L. Reille (1999) require careful interpretation. For example, a country may have a national surplus while experiencing nitrate pollution in some areas and nutrient depletion in others. The nutrient balance indicator needs to be used in conjunction with indicators on farm nutrient management, soil quality and water quality.

Livestock wastes contain substantial amounts of plant nutrients (see the section on Organic Materials). It is therefore evident that all sources of nutrients should be into account when determining rates of mineral fertilization.

Accounting systems based on the nutrient input and output are used in some European countries as a measure for the environmental performance of farms, particularly in countries with a manure disposal problem.

In Denmark, since 1994, farmers have had to prepare fertilization plans and the amount of nitrogen that may be applied to each type of crop is regulated. Another requirement is that 65% of the cultivated area must be covered by a green crop in winter. There are heavy fines in the event of infringement. In Germany a federal "Regulation of fertilizer use" model regulation came into effect in January 1996. The model must now be implemented in the individual Federal States. In Norway fertilizer plans are now compulsory. In the Netherlands a compulsory nutrient accounting scheme is starting in 1998. Nutrient applications over the maximum will be taxed. See O.L.H. Möller-Hansen et al. (1999)

Nutrient accounts may indicate a deficit as well as a surplus. The exercise would therefore be useful also in developing countries where soils are being mined of their nutrients. A substantial proportion of the nutrients which find their way into the manure produced by intensive livestock units originate from animal feed which has been imported from other regions of the world, thus depleting the nutrients in the soils of the exporting regions. But in many developing countries soils are also being exhausted just to provide a subsistence for their cultivators.

12. Health

12.1. Human health

12.1.1. Nitrates

Normally drinking water provides from 10 to 30% of the nitrate ingested, the remainder coming from vegetables, fruit and meat. The proportion of nitrate converted to nitrite also varies widely, but about 7% is typical.

Nitrate in drinking water is considered to be a public health problem because nitrate rapidly reduces to nitrite in the body. The nitrite oxidizes the blood haemoglobin which is unable to transport oxygen to the tissues; this can manifest itself in babies up to six months old, causing the blue-baby syndrome. It is normally due to the conversion by microbes of nitrates into nitrites in the feeding bottles as a result of defective hygiene. The occurrence of the syndrome is now rare, although, for some reason, cases still occur in Hungary and Romania.

Another concern is that nitrite may react with compounds in the stomach to produce N-nitroso compounds, particularly nitrosamines, which have tested positive in animal carcinogenicity experiments. Ingested nitrate is absorbed rather quickly from the upper gastrointestinal tract and most is subsequently eliminated in the urine. About 25% of the nitrate in blood is secreted by salivary glands, and the microbial flora of the oral cavity reduce some of it to nitrite.

It is never possible to prove zero risk, but it should be taken into account that doses of nitrosamines which have proved carcinogenic in animals far exceed those to which humans are exposed. No link to cancer in humans has been demonstrated.

In fact, there is now evidence that some nitrate is beneficial. Many pathogens are susceptible to nitrite under acid conditions. (T.M. Addiscott, 1996 and M. Golden and C. Leifert, 1997, C. Leifert et al. 1999).

Phosphate and potash have no known adverse effect on human health. Both elements are an important constituent of living organisms. Far from potash intake having any harmful effect, it may have a beneficial effect on human health in reducing hypertension.

12.1.2. Product quality

Some claim that crops grown with “artificial fertilizers” have less taste and are less healthy than, for example, organically grown produce. In fact, the plant does not distinguish between the original source, mineral or organic, of its nutrients - they are all taken up in the same chemical form.

However, according to a literature review by K. Woese et al. (1995), conventionally produced or fertilized vegetables may have a higher nitrate content compared with organically produced or unfertilized vegetables, especially those green and root vegetables which are nitrophilic. Vegetables of organic origin also tend to have a higher content of dry matter. Regarding all other parameters which determine nutritional values and sensory assessment, they noted that differences between the two systems were not significant or that the results were contradictory so that conclusions could not be drawn.

Over-fertilization should evidently be avoided but correct fertilization can have a positive impact on the quality of agricultural produce. For example, the mineral, protein and vitamin contents of crops may be improved if judicious fertilization corrects a previously existing inadequate level of nutrient availability. The baking quality of wheat, the brewing quality of barley and the colour, crispness and textural character of various vegetable crops benefit from appropriate fertilization, as can the calibre, taste and flavour of fruits. Potassium improves the tuber quality of potatoes and the sugar content of sugarcane. Sulphur increases the protein content in grain and the oil content of oil-seed crops. And so on.

12.2. Plant health

Fertilizer use at excessive rates has deleterious effects on crop growth. Examples are the lodging of cereals and the low sugar content of sugar beet resulting from excess quantities of nitrogen, nutritional disorders involving trace elements such as zinc due to excessive phosphate fertilizer and lime; impeded seed germination and seedling injury from too much soluble fertilizer salt adjacent to the seed row; the acidifying action of nitrogen fertilizer on soil, and increased incidence of plant and pest attacks with excessive nitrogen fertilizer. If the nitrogen application leads to acidification of the soil, it can induce aluminum and manganese toxicity if compensating lime is not applied.

As regards crop diseases, the most important impact of nitrogen is on vigour and plant growth. These two factors have an important impact on plant susceptibility to many diseases. Vigorous plants with rapid growth are generally more sensitive to obligate parasites and some pathogens are specifically more aggressive towards vigorous plants. However, most of the necrotic pathogens attack less vigorous plants with nitrogen deficiency. Balanced fertilization provides excellent protection. The time of application of fertilizers is important. A wrong timing may induce substantial growth of foliar parts of plants and maintain high humidity conditions in the crop canopy which are favorable to disease development.

Phosphorus application seems to favour plant protection against diseases, either by correcting a deficiency in soil phosphorus, and thereby inducing a better growth of the plant, or by speeding up the maturation process, disfavoring some pathogens like downy mildew that effects the young tissues.

Potash can increase the efficiency of use of other nutrients by plants, particularly of N. Potash has a beneficial effect on the quality of a wide range of crops, especially in terms of improved protein quantity and quality. Potash can decrease the incidence of plant diseases and reduce abiotic stresses, particularly cold stress. The element may have a direct action on pathogen penetration, lesion size and on inoculum density. An indirect effect of potassium on disease development is to stimulate the healing process (interaction with the scar parasites), to increase the resistance to cold, and also to delay the maturity and senescence of fruits. There is no known pollution or health hazard due to the use of potash fertilizers in agriculture. However, the application of potassium chloride to chloride-sensitive crops should be avoided, as should its use on certain saline soils.

Calcium may have an effect on the cell wall of plants by making them more resistant to pathogen penetration. A deficiency in calcium increases the sensitivity of plants to many fungi.

13. Biodiversity

Plant and animal communities may be directly affected by changes in their environment through variations in the quality of water, air and soil and sediments and through disturbance by noise, extraneous light and changes in vegetation cover. Such changes may directly affect the biosphere, for example habitat, food and nutrient supplies, breeding areas, migration routes, vulnerability to predators, or changes in herbivore grazing patterns, which may then have a secondary effect on predators. Soil disturbance and removal of vegetation and secondary effects such as erosion and siltation directly affect communities, and also lead to indirect effects by upsetting nutrient balances and microbial activity in the soil.

A common long-term effect is loss of habitat, which affects both faunal and floral communities, and induces changes in species composition and primary production cycles. For example, in some countries, population pressure is leading to the cultivation of unsuitable, fragile soils. Tropical forests, growing on soils that are usually highly weathered, are being felled on this account. A large proportion of the Amazon forest, for example, grows on poor soils, which deteriorate further and rapidly after deforestation. There is ample scope for improving agricultural productivity on more suitable land elsewhere in Brazil, thus avoiding the opening of new areas of the Amazon forest and even allowing some degraded areas to revert to natural forest.

In Indonesia, land settlement schemes have involved the felling of rain forest, following which soils have deteriorated rapidly. With adequate fertilization and good management practices, it has been shown that this land can be rehabilitated, thus avoiding the necessity of clearing additional rain forest and preventing further soil erosion and degradation.

Over-grazing is one of the major causes of soil erosion and the grazing livestock population is tending to increase. The increased production of fodder, with appropriate fertilization practices, is an excellent means of reducing the pressure of livestock on grazing land.

An indiscriminate reduction in fertilizer use would require farmers to use more crop acres to maintain, or increase, present production levels. This would require the use of less productive, more fragile soils.

Urbanization increases carbon emissions, whereas plants absorb carbon. Mannion (1997) noted, however, that, with intensification, the agricultural area is tending to decrease in much of the developed world, with corresponding increases for example in the forested area. This represents a net increase in the carbon sink. But in the developing world, the agricultural area is tending to increase, tropical forest is being transformed into agricultural land, and agricultural land is being lost to urbanization. This development clearly reduces the vegetative carbon sink, as well as resulting in a loss of biodiversity and genetic resources.

Currently progress is being made in many regions of the world in implementing diversity-friendly agricultural practices in soil conservation, withdrawing production from marginal areas, mastering chemical and nutrient runoff, breeding crop varieties which are genetically resistant to diseases, pests and abiotic stresses.

In the USA, the 1996 Farm Act created new programs such as the Environmental Quality Incentives Program, the Wildlife Habitat Incentives Program and the Farmland Protection Program. A number of other policy options intended to promote sustainability are in various stages of adoption. In 1996 the Agrienvironmental "Accompanying Measures" of the EU accounted for over 2 billion ECU, or about US$ 1.8 billion.

Until recently, the biology of what happens in the root zone - the rhizosphere - was relatively neglected.

M.J. Swift (1998) writes *"Soil management has been dominated by what may be termed an 'environmental management' paradigm. Crop production is seen as being regulated by its physico-chemical environment which can be altered and managed by physical means and the introduction of inorganic chemicals to suit the crop's needs. In recent years an alternative concept of 'biological management' has been emerging which focuses on the manipulation of biological populations and processes in soil as well as on its physico-chemical properties. At no location on the earth's surface has it been possible to assess the full biological diversity of the community of soil organisms.....The conventional approach to agricultural management seeks to bypass or even inhibit these biological regulators and often disrupts or destroys ecosystem stability and resilience. A biologically-driven approach provides a broader, ecological concept of soil management which is more readily translated across scales from plot to ecosystem and landscape. It is not only distinct from the green revolution physico-chemical paradigm but also from that of organic agriculture in that it does not eschew petro-chemically derived inputs but rather focuses on the efficiency of their use. Ecosystem science provides a framework which integrates the functional attributes of biological populations with their physical and chemical environments".*

It is known that the heavy use of nitrogen fertilizer inhibits the activity of symbiotic nitrogen fixing organisms such as *Rhizobium* species. If the legume plant is well supplied with nitrogen from the soil and/or mineral fertilizer, it is a less efficient nitrogen fixer; many legumes do not nodulate in the presence of a high soil nitrate level It has also been contended that fertilizer use, particularly nitrogen application, may inhibit the soil micro-organisms from mineralizing available soil organic matter.

Soil invertebrates (ants, termites, earthworms, spiders, millipedes, centipedes etc.) perform an important function in the maintenance of soil fertility. Mineral fertilizers have been accused of having an adverse effect on the earth worm population. It is certainly possible to demonstrate the lethal effects of fertilizer salts and anhydrous ammonia when applied in contact with a living worm. But only a small portion of the soil habitat occupied by worms is in direct contact with applied fertilizers, and consequently, the proportion of the total population detrimentally affected is small. A possible adverse impact on the earthworm population could result from the acidification of soils through the application of certain nitrogen fertilizers not balanced by liming; earthworms are inhibited by soil acidity. However, some researchers have established that the greater supply of fresh organic material obtained through fertilization is of far greater significance to the earthworm. Size and numbers of earthworms invariably increase as soils are brought from a low to high level of fertility through effective fertilization.

The circumstantial evidence of the experiments in which mineral fertilizers have been applied continuously for a very long period of time, in a fully sustainable system, a priori indicates that correct fertilization practices do not harm soil flora and fauna essential for crop production.

14. Organic materials

Organic materials influence plant nutrient availability by:

- providing plant nutrients; although the nutrient content is very variable and low; less than 2% total nutrients in cattle manure, about 1% in slurry,
- providing a source of carbon and energy for microbial activities,
- controlling net mineralization-immobilization patterns,
- increasing soil organic matter, which can improve the structure, water storage and cation exchange capacity of soils,
- possibly improving the availability of P.

An application of up to 5 t/ha of cattle manure contains sufficient N to match the requirement of a 2 t crop of maize but cannot meet the P requirements. The average maize yield in the USA is about 8 t/ha.

It is also necessary to distinguish between organic material produced on-site, whose only addition to the soil capital is nitrogen fixed by legumes, and organic material produced elsewhere, which brings in a net addition of nutrients.

Mineral fertilizers should not be used as a substitute for manure where manure is available. If there are housed animals on a farm, the manure produced has to be disposed of and this can best be done by applying it to the fields. It should then be supplemented with fertilizers to arrive at the total nutrient requirement of the crop. However, globally, the availability of manure is far from being sufficient to provide the quantities of plant nutrient required by crops. Manure and fertilizers are complementary, not competitive.

In reviewing the topic of organic materials, it is useful to differentiate between the situation in cool, temperate climates and that in Mediterranean, sub-tropical and tropical climates.

14.1. Temperate and cold climate zones

Johnston (1997) reports that for many years, based on experiments in the UK, the importance of soil organic matter was played down. Yields of crops were the same on soils given NPK fertilizers and farmyard manure (FYM) provided the appropriate amount of N fertilizer was given. This was so up to the 1970s, even though the annual application of 35 t/ha FYM had resulted in a two and a half fold difference in soil humus levels between fertilizer and FYM treated soils. However, recent results suggest that humus does play an important part in soil productivity. To achieve the high yield potential of the new cultivars all factors affecting growth, including the root environment within the soil, have to be optimum. There are also strong indications that, in the field, soil with more organic matter had a better structure and roots found sufficient P for optimum growth at lower concentration of available P, than on soils with poorer structure. The effect has become evident more recently as high yield levels are reached.

Large amounts of organic matter have to be added to soil to increase appreciably soil organic matter in the short term. In normal farming systems the effects can be small. For example, at Rothamsted, alternating three years' grass leys with three years' arable crops increased soil organic matter by only 10% after 18 year (A.E. Johnston, 1973).

It is traditional, good agricultural practice to make optimum use of organic materials. Unfortunately, a substantial proportion of the nitrogen content of manures is lost to the environment during storage and handling. Quantities which are effectively applied must be taken into account when making fertilizer plans for crops.

Manures are bulky and hence expensive to transport and labour-intensive. They are often unpleasant, they may contain toxic elements, pathogenic organisms and antibiotics originating from animal feed. Furthermore, it is more difficult to utilize effectively the nutrients, especially the nitrogen, contained in animal manure than those contained in mineral fertilizers. The nitrogen content of manure shows considerable variation over time, between livestock species and according to the type and quality of fodder supplied to the animals. The ratio of nutrients often does not match that required by either crops or grass. The nitrogen (N) in animal manure occurs in both inorganic and organic forms. Lastly, and perhaps most importantly, mineralization of the organic nitrogen fraction depends on the temperature and moisture content of the soil, cultivation practices, and the overall organic matter content. It is therefore not possible to control the release of nitrogen to the crops. In Europe the contribution of nitrogen to leaching and the input into water is significantly higher from animal manure and slurry than from correctly-applied mineral fertilizers.

The initial phosphate and potash content of manure and slurry is largely present in the material applied to the soil, but there are substantial losses of nitrogen. In Europe it is estimated that 37% of the original nitrogen content of manure and slurry is lost as ammonia before it is added to the soil. This comprises 12% lost in winter storage, 7% in summer storage and 18% in spreading (EFMA, 1997). It is difficult to obtain accurate estimate of losses during the growing season but work at Rothamsted in the UK indicates that they are substantial and much greater than losses from applied nitrogen fertilizer (A.E. Johnston, personal communication). During winter the mineral N in FYM treated plots, susceptible to leaching, was much greater than that in NPK treated plots (D.S. Powlson et al. 1989).

There is much evidence that, up to the economic optimum rate of application, very little of the applied fertilizer nitrogen is leached during the crop growing season. The applied nitrogen is taken up by the plant and some may be stored in the soil. The nitrogen in that part of the plant which is not harvested, removed or burned, also goes into the organic matter of the soil. Some of this nitrogen will become available to subsequent crops but with certain agricultural practices, such as leaving the soil uncropped out of season, the nitrogen stored in the soil organic matter may be released through denitrification, and leached.

14.2. Tropical and subtropical zones

The soil content of organic matter is often relatively low under warmer climatic conditions due to oxidation, and the benefits of increasing the organic matter content of soils are clearer than under temperate conditions. Apart from its plant nutrient content and function in improving soil physical properties, there is evidence that organic material can help to offset the effects of soil acidity and aluminium toxicity, and it may supply soil sites which hold readily available phosphate for plant uptake. Trace element deficiencies are increasingly common under more intensive growing conditions and, in the absence of more precise assessments, organic material from outside sources may incidentally provide some of the needs.

In trials in India, the application of manure together with mineral fertilizers has given a clear yield advantage. Long-term experiments showed that after 20 years of ammonium sulphate application, the crop yield declined to zero. NPK plus lime sustained the highest yield and FYM could maintain stable but lower crop yields. Where combinations of NPK and FYM are given the latter could contribute 20% to total production.

In Burkina Faso, fertilizers, manure and a mixture were compared over 11 years on an Oxisol. All treatments increased maize yields during the first 3 to 4 years. Then during the 4-6 year period yields decreased for all treatments. The mixture gave higher yields than fertilizers alone over the 11 years. Fertilizer increased acidity. When soil acidity and exchangeable aluminium were neutralized by liming, the yield increased. Manure helped to limit the consequences but is incapable of neutralizing all the acidity induced by the fertilizer.

Speaking about the situation in India, N.E. Borlaug (1996) pointed out that there was not enough organic manure available in India to supply sufficient nutrients to produce the food grain needed to feed the population. The supply of nutrients from organic manure was insufficient to compensate for nutrient depletion and the nutrient supply from this source was unlikely to improve due to the competing demand for alternative uses such as fuel, fodder and feed. Comparing the situation in China with that of India, he said that one of the reasons for the higher use of organic matter in China was the fact that the government subsidized coal, thus reducing the need to use organic materials as fuels.

In many African and Asian countries animal wastes and crop residues have competing uses and the problem is one of a shortage rather than a surplus as in Europe and elsewhere. The systems produce too little biomass, and much of what is produced, is consumed by grazing animals and then deposited elsewhere. The return of organic matter to the soil is negligible.

Precautions to avoid the application of toxic substances in organic amendments must evidently be taken. Also the application of manure under anaerobic conditions, for example in rice paddies, should be avoided to prevent the release of methane. Apart from this, the integration of mineral and organic fertilization is strongly recommended.

14.3. Composts

FFTC (1997) reports, concerning the Asia and Pacific region, that "*there is also an urgent need to reduce pollution from agricultural wastes. One means of dealing with them is to compost them and use the compost as fertilizer. Very efficient composting methods are required for this purpose. Malodorous gases emitted during the treatment of livestock manure or agro-industrial waste can cause serious air pollution. There are various means of controlling such odours.*

There are a number of composting plants. Their products are often of poor quality and also contain unknown quantities of chemical fertilizers, in proportions unsuited to crop needs. There is an urgent need to define standards for organic fertilizers.

Because of the difficulty of quality control, most commercial organic fertilizers are not covered by the type of national standards which govern the quality of chemical fertilizers".

15. Resources

15.1. Resource availability

15.1.1. Energy

Fertilizers, especially nitrogen fertilizers, require fossil fuel energy to manufacture, and some to transport and apply. It is estimated that worldwide agriculture uses about 5% of global energy consumption. This includes nitrogen fertilizer production, which is estimated to account for less than 2% of annual world energy consumption. This estimate of 5% excludes the transport and processing of the agricultural produce which is more energy intensive; for 1 kg of bread, growing the wheat takes about 20% of the energy used, while milling, baking and distribution account for 80%. Thanks to photosynthesis, in the case of cereals and root crops the harvested energy is substantially greater than the energy input. In the case of intensive horticulture the energy input may be higher than the energy output.

In France (Commissariat Général du Plan, 1997), in 1995 the manufacture of fertilizers accounted for 1% of total energy consumption. Agriculture, including the application of these fertilizers, accounted for 1.6%. The food processing industry, conservation and preparation accounted for a further 8%.

The energy requirements for the manufacture of fertilizers may be met by natural gas, oil, naphtha or coal depending on the cost and availability in the region of the world where the ammonia is produced. In 1995 known coal reserves amounted to about 450 years of 1995 production, natural gas 66 years and petroleum 43 years. Additional reserves tend to become available as time passes, due to new discoveries and/or technical progress. For example, in 1978 the US natural gas reserves:production ratio indicated a 12-year supply. 17 years later the USA still had a reserve:production ratio indicating about 9 years supply.

15.1.2. Phosphate and potash

Phosphate deposits are widespread throughout the world but their economic recovery depends on the cost. The most accessible and higher quality rocks tend to be mined first; according to IFA statistics the average P_2O_5 content of the 125 Mt of phosphate rock mined in 1980 was 32.7%, whereas that of the 141 Mt mined in 1996 was 29.5%. At the present rate of phosphate rock production and with production costs of the same order as at present the “reserves” are sufficient for at least 80 years, and at somewhat higher cost for 200 years. The “resources” which could be economically mined at higher cost are much greater. On most soils almost all the phosphate not taken up by the crop is retained in the soil. It is possible that techniques for the recovery of this phosphate may be developed in due course. Phosphate losses by soil erosion can be minimized by following Codes of Good Agricultural Practice.

There is no concern about potash resources, the known high quality reserves being sufficient, at present rates of use, for several hundred years and resources, recoverable at higher prices for at least a thousand years. Nevertheless, prudence in the use of phosphate and potash reserves is advisable since there are no known replacements.

15.1.3. Land

There is evidently a limit to the area of fertile agricultural land in the world. Even in 1975, according to an FAO survey, 54 countries could not feed their populations with traditional methods of food production, and the number has increased significantly since that date.

Furthermore, substantial areas of good agricultural land are being lost each year due to urbanization and deterioration, the latter due, for example, to salinity, erosion and desertification. It is estimated that every year soil erosion and other forms of land degradation rob the world of 5 to 7 million hectares of farming land (FAO, 1995).

Apart from areas of fertile land purposely idled in the USA and West Europe, there are some reserves of land which could be cultivated, particularly in Sub-Saharan Africa and South America, but three quarters of this land suffers from soil and terrain constraints. Much is under forest. The amount of additional fertile, well-watered, non-erodable, unforested land that can be brought into agricultural production at low cost is very limited. Somewhat more land could be brought into production with significant investment in reclamation or irrigation, but the rate of increase of irrigation is slowing because water is another increasingly scarce resource.

In any case, over the last 50 years, the increase in agricultural production has been achieved mainly by increasing crop yields - the overall 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. But the world's farmers were able to grow about one billion tons more cereals in 1990 compared with 1960. According to FAO, four-fifths of agricultural growth in developing countries is likely to come from intensification (increased yields, multiple cropping and shorter fallows.

15.1.4. Water

Agricultural irrigation uses over 70% of the world's supplies of developed water and in the drier farming regions crop production is heavily dependent on irrigation practice. Agriculture is facing increased competition for limited water resources. During the next three decades, there will be an increasing number of water-deficit countries and regions including not only West Asia and North Africa but also some of the major agricultural producing regions of the world such as the Indian Punjab and the central plain of China. The efficiency of utilization of irrigation water is often low and around 50% of the increase in demand for water could be met by increasing the effectiveness of irrigation (D. Seckler et al., 1998). It is therefore extremely important to improve the efficiency of water use and it is established that something approaching the economic maximum of plant material ensures high water use efficiency. This objective will be achieved only with a well nourished plant. Other experiments have shown that the return from nitrogen is much increased by irrigation (G. Cooke., 1966, pages 245 -246, J.C. Ignazi., 1992 and J.S.P. Yadav et al., 1998). The dependence of water use efficiency on plant nutrient supply is reviewed by J.G. Davis, 1994. In fact any input factor that increases economic yield will improve water use efficiency (FAO, 1984).

UNDP's 1998 Report

UNDP's 1998 World Human Development Report emphasizes the fact that it is the poor which are hit hardest by environmental degradation. Past deterioration of resources worsens current poverty. This renders very difficult the important tasks of the preservation and restoration of agricultural resources, reforestation, prevention of desertification, the fight against erosion and soil nutrient replenishment. It is a vicious circle. Individuals confronted with poverty are obliged to over-exploit resources, which risks exhausting them, which in turn increases their poverty. The poor will be increasingly pushed to live on fragile land; by the end of the next decade it is possible that a billion poor people will have to live on fragile land as against 500 million today.

The problem of land degradation is most serious in Africa and Asia, with two thirds of the world's poor. The problem of land degradation is worse in arid areas. And this is not particular to developing countries. The continent which has the largest area of arid land subject to desertification is North America (74%), just ahead of Africa (73%).

Deforestation is another problem. Almost a third of the earth's forest have disappeared and about two thirds of those which remain are subject to serious modifications. Forests retain and regulate water and their destruction can lead to floods and drought.

Today about a third if the world's population depends on renewable resources. By 2025 a substantial proportion of the population of sub-Saharan Africa and South Asia will depend largely on these resources, as will a substantial number in Latin America and the Caribbean. The area of arable land per person is likely to be half the present low level of 0.27 ha. By 2050 more than two billion people will live in regions with a land shortage, due to desertification and degradation, in particular in South Asia and sub-Saharan Africa.

In the world as a whole, the use of water is increasing rapidly. By 2025 it will have increased by 40%. By 2050 the number of people suffering from a water shortage will increase from 132 million to between 1 and 2.5 billion. Almost two thirds of the world's population will be confronted with a moderate or high shortage of water. Some believe that water will be an important cause of wars in the 21st century.

15.2. Recycling

There is, therefore, no immediate problem with the availability of the raw materials for fertilizers but waste should evidently be avoided, for both economic and environmental reasons, and where possible nutrients should be recycled if this can be done safely.

Animal and human waste, and particularly animal wastes, contain substantial amounts of plant nutrients. Certain industrial wastes contain elements which are required as micro-nutrients, and can be used to manufacture micro-nutrient fertilizers. According to UNDP (1998) if present trends continue the production of wastes in the world will increase five times by 2025, increasing pollution and the health risks which are associated with pollution especially in developing countries.

Recycling human and animal waste in agriculture has a long history. Among the benefits of the application of organic wastes in agriculture are improvements in soil fertility, the premium paid for organic vegetables, and the conversion of waste materials into useful resources. The ready availability of mineral fertilizers is considered by some as a disincentive to the rational use of organic wastes.

In West Europe, livestock wastes account for 30% of the nitrogen, 48% of the phosphate and 63% of the potash available for application to crops, much of it coming from intensive livestock production units. However, whereas some regions have a large over-supply of livestock wastes, other regions have an under-supply, and the material is neither easily nor economically transportable from one region to another, even within the same country. According to EFMA (1997), in West Europe non-livestock wastes account for only 3% of the nitrogen, 4% of the phosphate and 1% of the potash available for agriculture. The EU Parliament has recommended that energy production from small-scale biogas plants should be promoted as a useful way of disposing of animal waste.

In the USA it is estimated that in 1992 of total available plant nutrients, animal wastes accounted for 10% of the nitrogen, 24% of the phosphate and 22% of the potash. However, because of transportation costs use of animal waste as fertilizer is economically feasible only if on-farm or nearby sources exist, and thus the waste from intensive livestock units is normally applied on a limited area near the unit.

Manure and slurry have a low plant nutrient content compared with mineral fertilizers, they are expensive to transport and unpleasant to handle and spread. Losses to ground water and the atmosphere are substantial. They are very variable in quality depending on the species of animal, type of feed, storage conditions etc. A large proportion of the nitrogen contained in manures is insoluble initially and only released for crop uptake when the organic matter is broken down, which can take from a few weeks to several seasons. In consequence it is difficult to assess the amount of nutrient in these materials which should be included in the fertilizer programmes. Norsk Hydro, Norway, is developing an anaerobic digestion system for animal manures in order to convert most of the nitrogen into an available form and provide a more consistent product.

In most developed countries, the disposal of such wastes is increasingly controlled by legislation. Organic farming aside, it is the disposal of manure and slurry which is the main environmental issue, rather than of recycling. Evidently, where manure and slurry are applied, it is important to take their nutrient content into account when determining rates of mineral fertilization - until the mid-1980s this was often not the case.

Industrial waste is used as a source of micro-nutrients in mineral fertilizers. Only a small proportion of mineral fertilizers. The beneficial re-use and cycling of industrial wastes, where this can be done safely, is normally encouraged by the authorities but care must evidently be taken not to introduce toxic substances.

The impetus to making better use of waste is coming mostly from the fact that, in most industrialized countries, it is becoming increasingly difficult and expensive to find landfill sites for solid waste. They represent a danger for agriculture. This was highlighted by a collection of reports from thirteen European countries for an FAO/ECE meeting (1994), on the pollution of agriculture from urban and industrial origins. The cheapest and most convenient means of disposal of these wastes is in agriculture. The other alternative being incineration, which is more expensive. The main problem is in fact to dispose of manures and sewage sludge safely. Because of the pollution possibilities, under the EU Nitrates Directive, due to the risk of pollution from manure, the EU Commission effectively requires Member States to introduce regional limits on stocking density by limiting the addition of nitrogen from animal manure to 170 kg per hectare per year. In addition, the periods in which it is acceptable to apply animal manure are strictly defined.

The disposal of sewage sludge in agriculture, even if free of toxic materials and harmful pathogens, often poses problems for farmers. Food processors and retailers increasingly have contracts with farmers, which stipulate that sewage sludge may not be applied.

16. Land spared

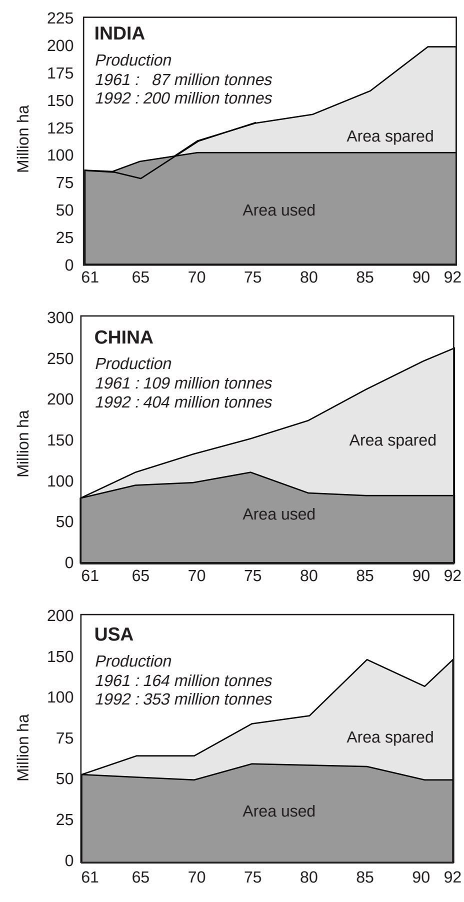
Mineral fertilizers and land are substitutable in the sense that an increase in the use of fertilizers permits a reduction in the area of land cultivated, and vice-versa. The use of mineral fertilizers has environmental costs but all farming, as most of man's activities, has an environmental impact. Overwhelmingly the evidence is that mineral fertilizers are necessary for the welfare of mankind. There are environmental risks but they are minor in relation to the benefits.

N.E. Borlaug (1997) stated:

"*Take the cases of the United States, India and China as examples. In 1940, when relatively little inorganic fertilizer was used, the production of the 17 most important food, feed and fiber crops in the USA totaled 252 million tons from 129 million hectares. Compare these statistics with 1990, when American farmers harvested approximately 600 million tons from only 119 Mha - 10 Mha less than 50 years before. If the United States attempted to produce the 1990 harvest with the technology that prevailed in 1940, it would have required cultivating an additional 188 million hectares of land of similar quality. This theoretically could have been achieved either by ploughing up 73% of the nation's permanent pastures and rangelands, or by converting 61% of the forest and woodland area to cropland. In actuality, since many of these lands are of much lower productive potential than the land now in crops, it really would have been necessary to convert a much larger percentage of the pasture and rangelands or forests and woodlands to cropland. Had this been done, imagine the additional havoc from wind and water erosion, the obliteration of forests and extinction of wildlife species through destruction of their natural habitats, and the enormous reduction of outdoor recreation opportunities. Impressive savings in land use have also accrued to China and India through the application of modern technology to raise yields. Had the cereal yields of 1961 still prevailed in 1992, China would have needed to increase its cultivated cereal area by more than three fold and India by about two fold, to equal their 1992 harvests. Obviously, such a surplus of agricultural land was not available.*"

Land that Indian, Chinese and U.S. farmers spared as a result of rising cereal yields. Area used is the land actually harvested; area spared is additional land that would have been needed if 1961 yields had not increased.

Source : Norman E. Borlaug (1997).



17. Partners in environmentally sustainable fertilizer use

Ideological disputes on the use of mineral fertilizers should not be allowed to distract attention from the main problem, which is that the inefficient use of mineral fertilizers represents a waste of resources, a large economic loss and may contribute to significant environmental problems. Improvements in the efficiency of fertilizer use are also likely to reduce the environmental impact.

In the developed countries the efficiency of fertilizer use is increasing, and should continue to increase, but this is not the case in most developing countries. The aim must be to optimize agricultural production per unit of fertilizer applied, while applying the required quantities of fertilizers to satisfy the world's agricultural requirements. How could this be achieved?

Fertilizers are now indisputably in the centre of the debate on food, environment and society. Farmers apply the fertilizers in the field. Fertilizer companies also impact on society and the environment through the manufacturing process. In between is the entire supply and distribution chain, with a multitude of organizations, institutes, and individuals. There is also research/development and marketing. What contribution can each of these elements make to the global movement towards sustainability that world society is now attempting?

The fertilizer industry consists of many interlocking organizations, manufacturers, distributors, institutes, programmes and associations, as well as individuals. Each organization is to some extent constrained in what it can do because part of the supply chain is outside its control. Yet there is no common view of how synergies can be created, nor is there an outline of useful roles for each group so that their contribution adds to a collective movement in the direction of sustainable development.

Coordination within the fertilizer industry is the role of associations such as IFA, but the fertilizer industry cannot be considered in isolation. It is an important, but not the only agricultural input and the purpose of all the inputs is to enhance the production of agricultural products. The market for the latter is subject to the demand of consumers. Like the fertilizer industry, therefore, also consumers have a responsibility to society and to their environment.

At least twelve categories of institutions are involved in the establishment of environmentally sustainable fertilizer use:

1. Farmers' associations.
2. Fertilizer manufacturers and distributors.
3. Fertilizer associations, national and international.
4. Other input suppliers and their associations; seeds, plant protection products etc.
5. The agricultural marketing sector, food processors, distributors and retailers.
6. Banks and credit institutions.
7. Educational establishments.
8. National Governments. Ministries of agriculture and of environment - but other Ministries such as planning, health and labour have a regulatory role.
9. Governmental research and advisory services are particularly relevant to the fertilizer sector.
10. Inter-governmental and United Nations organizations such as the European Commission, FAO, OECD, UNEP, UNIDO, World Bank.

11. Non-government organizations.
12. Donor organizations - bilateral and multilateral.

In the case of mineral fertilizers, there are significant problems associated with their under-use, over-use and incorrect use. In many countries there are inadequate research and advisory activities in place. Neither the private sector nor the public sector alone can resolve these problems. Cooperation and participation by the entire supply chain is needed for sustainable development.

In some fields, a more global vision is being adopted. For example, the 1994 inter-governmental conference in Cairo on world population examined the food-population equation not in simple rich-poor, north-south, hungry-overfed terms, but as a series of complex relationships between (1) development to maintain and enhance living standards (2) reduced population growth and (3) greater environmental protection.

The International Agri-Food Network

Whereas the focus of environmental pressures on the fertilizer industry in the 1970s and 1980s was essentially localized, with problems such as those associated with eutrophication of surface waters by phosphates and nitrates, and nitrates in drinking water, the new environmental agenda is more regional and global in nature. For example, the impact of N_20 emissions, not just from fertilizer production, but also from agricultural activities in general, is of increasing concern in the analysis of greenhouse gases and climate change. Other issues and factors influencing the drive towards sustainable agricultural production concern the growing significance of biotechnological advances in crop production and the use of waste in modern farming systems.

None of these issues is specific to the fertilizer industry, neither as causative factors nor in potential solutions.

As the international community, including the United Nations, addresses these global problems, through organizations such as the FAO, the UN Commission on Sustainable Development-UNCSD, the Conventions on Biodiversity and Climate Change, etc., it is increasingly important for all agribusiness sectors to coordinate their activities to ensure that their role is acknowledged objectively, alongside others such as environmental NGOs which regard organic agriculture as the only solution to sustainable food production.

In an effort to integrate fertilizer issues with those of other industry sectors, such as seeds, crop protection, farmers' organizations and cooperatives, livestock and food distribution and processing, IFA was instrumental in forming the International Agri-Food Network, IAFN, an informal panel of all elements in the food chain.

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About IFA and UNEP

IFA - International Fertilizer Industry Association

IFA, the International Fertilizer Industry Association, comprises around 500 member companies world-wide, 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 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 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

The Production and Consumption Unit of UNEP DTIE 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.

This Unit 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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