NEW TECHNOLOGIES IN SOIL FERTILITY MAINTENANCE PRIVATE SECTOR CONTRIBUTIONS

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General Aspects of Soil Fertility

It is generally perceived that the soil, through its various physical, chemical, and biological processes, plays an essential role in the growth of plants. This is incorrect, however, in that, given water, air, and mineral salts, plants grow perfectly well without soil. Intensive commercial vegetable production systems are based essentially on hydroponics with the soil providing mainly physical support for the plant.

This being said most crop production will continue to rely mainly on the soil as a physical, biological, and chemical environment for the plant roots with all three of these elements interacting, often in a complex way, to affect root growth and health and thereby determining the final yield of the crop. The skill of the farmer lies in his ability to eliminate soil constraints to growth and to exploit these interactions to the degree possible while practicing sound soil erosion control measures.

The Need for Plant Nutrients

Historically, the small farmers of the world have taken amazing steps in selecting crops, varieties, and cropping systems to fit their particular ecosystems. A good example is the existence of cropping systems using traditional varieties of rice that are season and period fixed and that, in the case of deep water rice, exhibit facultative elongation.

The relatively rapid spread of maize and cassava in Africa and of the potato in Europe, all of which were imported from Latin America, illustrates the constant search for newer and better crops and cropping practices and the ready adoption of useful technologies by the farming community even in the absence of formalized research and extension activities. The search for means of safeguarding and improving the soil resource base has also been the historical goal of many farmers. Extremely well-developed crop residue recycling systems, with or without an animal component, were developed in Europe and Asia in areas of high population density, and on all the continents long-term rotations and the use of wood ash and leguminous crops were features of farming in many areas. All these systems, which are rich in their variability, developed presumably as a response of the farmer to his environment and from a sense of stewardship. Unfortunately, population pressure is causing the

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collapse of many systems which were sustainable when population pressures were low, with consequent severe damage to the soil resource base.

The world's highly productive cropping systems capable of handling the increasing demand for food are essentially already in place. They are based on modern technologies; thus yields and profitability depend for the foreseeable future on fossil fuel-based technologies.

As with the collapse of the traditional farming systems, the pressures for increased production have caused abuses of the modern technologies, and both industry and the farmer now face the environmentalists' pressure to change. Much of this pressure is aimed at a major reduction in pesticide use and, unfortunately, also in fertilizer use. The word "unfortunately" is used deliberately; whereas pesticides are essentially synthetic organic molecules, many of which do not exist in nature, fertilizers are sources of nutrient ions that are needed by plants and that already exist in all soils.

Harwood (1990), in his review of sustainable agriculture, highlights three points on which there is universal consensus: (a) agriculture must be increasingly productive and efficient in resource use; (b) biological processes within agricultural systems must be much more controlled from within (rather than by external inputs of pesticides); and (c) nutrient cycles within the farm must be much more closed. The first point is a truism; the second point clearly anticipates that pesticide use must be and will be increasingly based on integrated pest management; and the third point highlights the whole problem of sustainable soil fertility because nutrient cycles at the field, the farm, and even at the agroecological zone level are not closed and cannot be fully closed.

Agricultural production inevitably results in the exportation of nutrients from cropped lands. Increasing populations and intensified cropping imply increased nutrient exportation. As a result, many of the world's cropped areas are in negative nutrient balance. The collapse of traditional farming systems, the increasing encroachment of agriculture into fragile environments, and the abuse of modern high-input technologies have led to serious environmental and soil degradation problems all because of the drive for increased crop production.

The scientific use of fertilizer is an essential complement to on-farm sources of nutrients, including biologically fixed nitrogen, crop residues, and manures, if a sustainable agriculture that can meet the increasing demands for food is to be achieved.

In spite of an apparent slowing of yield growth (the United States maize crop, for example), conventional technology with fertilizer and improved crop cultivars, particularly as related to pest resistance, will remain the primary source of potential growth in crop production over the next quarter of a century. The achievement of production gains will depend increasingly on appropriate knowledge and information dissemination. Beyond this time period, advances in conventional technology will be inadequate to sustain the current demand trend (Ruttan 1990).

Sources of New Technologies in Soil Fertility Maintenance

New technologies are research derived, however, it must be pointed out that agricultural research by the private sector is concentrated primarily in the more developed countries, and even in these countries there is almost a continuum of research activities from government centers to the private agricultural input companies (Pray and Echeverria 1991). This is particularly true for soil fertility research, which receives major contributions from universities and national research institutes.

Until recently, this has been the situation in the United States also; the U.S. Department of Agriculture (USDA), the land grant colleges, and the federally funded National Fertilizer and Environmental Research Center (NFERC) of the Tennessee Valley Authority (TVA) have been key players in the areas of soil fertility maintenance and improved fertilizer technology. In contrast to the United States, the major European producers did have internationally recognized agricultural research stations, for example, Jealott's Hill (ICI) and Limbergerhof (BASF). However, the main efforts of the fertilizer producers in both North America and Europe, in terms of field-level technologies, were directed toward excellent information flow and the development of brand loyalty.

Nutrient-specific "trade associations," whose objective is the commercialization of the respective nutrients, have been formed. The International Potash Institute in Basle, Switzerland, supported by potash producers in Europe and the Near East, the Potash and Phosphate Institute (PPI) in Atlanta, Georgia, supported by the American potash and phosphate industries, and the Canadian-based PPI are very active in the extension of scientific information that relates to fertilizers generally and to potash and phosphate in particular. The Sulphur Institute, in Washington, D.C., is also very active in pressing the agricultural value of sulfur.

The role of trade associations in the development of agricultural technologies is often underestimated, but there is no doubt that they bring much dynamism to information diffusion through publications, meetings, and field demonstration work.

Soil Fertility Maintenance

The key physical, chemical, and biological components of soil fertility maintenance are the following:

- Control of erosion
- Maintenance of organic matter
- Maintenance of soil physical properties
- Avoidance or the reduction of the effect of toxicities
- Maintenance of nutrients and optimization of their supply to crops.

These components will be discussed in this order with special attention to nutrients, which is the key topic. The policy and socioeconomic components of soil fertility maintenance are not addressed in this paper, but Appendix 1 draws attention to the possibility of oversimplification of problems when addressed solely in terms of private sector involvement.

Control of Erosion

All the available techniques for controlling soil losses have been applied for many years, even hundreds of years, often in a very successful way and often alongside practices that are examples of what not to do. Sound stewardship of the soil, however, is not a universal goal; the needy and the greedy often have no interest in long-term and often low-payoff investments. In general, practical soil erosion control programs have been initiated by governments, for example, the U.S. Soil Conservation Service (SCS).

The relationship between the private sector and government is illustrated in the key role played by the private sector in effecting a major fundamental change in U.S. farming practices in the area of conservation technology (see appendix 2 for definitions).

The initial impetus to use reduced tillage methods (no-till is the extreme) was the simple economic fact that farmers knew that every trip across a field with a tillage tool represented an investment in time and dollars (AAVIM 1983). However, the 1985 Food Security Act, which makes conservation practices on certain erosion-prone land an eligibility requirement for participation in many USDA programs, put economic teeth into the developments. Forty percent of the net income for all agriculture in 1987-88 came from these USDA programs. Conservation tillage needed new equipment and new herbicide and fertilizer practices, and the farmer and the private sector generally were quick to respond to these needs (Triplett 1988).

Traditional moldboard plowing is an effective means of controlling weed, insect, and disease problems, and so the shift to reduced tillage practices tends to necessitate the use of more chemical pesticides. Fertilizer placement becomes more critical and thus leads to an increased demand for innovations in product and application equipment.

One of the key components of erosion control is the rapid establishment of ground cover in order to reduce rainfall impact on the soil surface; thus, the selective encouragement of weed growth combined with a sound herbicide application program is a practical proposition in some areas.

The latest actual figures (1990) on tillage practices based on the surveys of the Conservation Technology Information Center (CTIC), cited in *No-Till Farmer* (Mid-January 1991), show the following:

Total ridge-till	3,037,899	acres
Total no-till	16,861,810	acres
Total minimum-till	56,382,031	acres
Conventional till	207,742,086	acres

In 1972, only 3.4 million acres of American farmland were being no-tilled; thus progress is evident. There are problems, however, concerning the relevance of the no-till and even minimum-till technology to varying soil conditions.

The involvement of the private sector in conservative tillage development is illustrated by the fact that the CTIC, which is supported by the Soil Conservation Service of the United States and the Environmental Protection Agency, receives about one-third of its budget from the private sector. The Executive Committee of this organization draws on high-level executives from such companies as du Pont de Nemours, American Cyanamide, Allis Chalmers, and John Deere. This involvement reflects the impact that changes in tillage practices have had and will have on fertilizer and pesticide use and on agricultural equipment needs, and it also illustrates the readiness of the private sector to become involved in any activity that may affect their market position--in this case, government directives and subsidies aimed at soil erosion control.

Maintenance of Organic Matter

In the natural uncultivated condition, the regular addition of plant detritus that is incorporated into the soil by soil organisms leads to the development of higher levels of soil organic matter (humus), which, in turn leads to improved soil structure and improved plant nutrient and water-holding properties and greatly increased storage of soil nitrogen (N). The final level of organic matter in a soil is a characteristic of a particular soil; generally, higher rainfall increases the level while higher temperatures decrease the level.

Once a soil is cultivated, the level of the soil organic matter declines. In turn large quantities of inorganic N are initially liberated, the physical stability of the soil is reduced, and its capacity to act as a reservoir for plant nutrients and soil moisture is diminished, and, of course, large quantities of nutrients are removed in the harvest.

These are facts that account for the serious destruction of structurally fragile soils, however, for most of the productive soils of the world, these facts have been of little interest to the farmer because improved cultivation techniques combined with improved crop varieties and fertilizer use have achieved major increases in yields despite soil and organic matter losses.

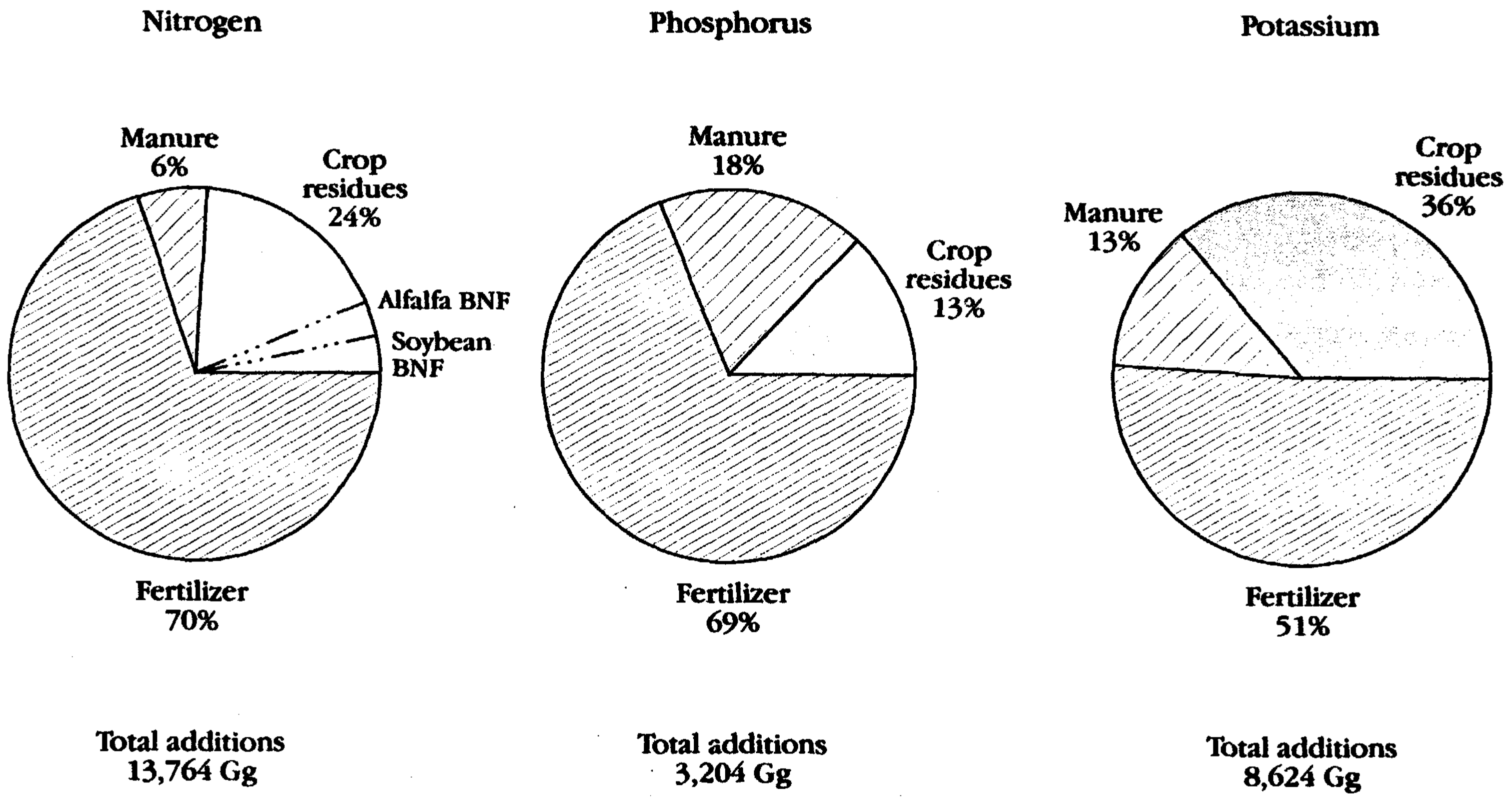
Almost coincidentally, the improvements in the practice of crop residue recycling in high-yielding areas due to improved machinery have led to the situation where, with maize for example, up to 10 tonnes of dry crop residue--trash, stover, cobs, and roots--is returned to each hectare harvested. Even these high levels of organic matter return, however, have only a small impact on soil organic matter levels. Barber (1979) showed for a high-yielding maize plot that at least 6 tonnes a hectare of residues was required to maintain organic matter levels. Of particular interest in this study was the fact that roots and root exudates were shown to contribute significantly to the maintenance of organic matter levels.

The conclusion therefore must be that high soil fertility resulting in higher production of crop residues that are correctly handled in the field will help to maintain soil organic matter but often at levels below those of the soil in its natural uncultivated state.

The use of organic materials as sources of plant nutrients is well developed in many countries, and the use of biological nitrogen fixation (BNF) for the generation of soil nitrogen is also widely practiced. Figure 1 shows the breakdown of the source of the three major nutrients in the agriculture of the United States. The figure shows the overriding importance of fertilizers in high-production agriculture.

Research on soil fertility to date has been heavily oriented to the use of fertilizers as the profit maker and to type, rate, timing, and placement as important components of the efficiency of their use. However, organic manures have always been valued for their nutrient contents and have been and still are costed essentially in terms of their content of available N, P_2O_5, and K_2O. The value of organic manures per se in improving soil structure, cation-absorbing capacity, and so on, also has been appreciated but only as a positive bonus from their use as a source of inorganic nutrients (see table 1). In practice, with intensive animal production systems, manure becomes more of a disposal problem than a valued farm input. Similarly, with crop residues--the easiest and often a beneficial way of dealing with them is by burning, but the concern over the environment and the value of surface crop residue management in controlling soil erosion have led to major improvements in handling.

Figure 1. Additions of N, P, and K to Cropland Soils of the USA from Fertilizers and by Return of Crop Residues and Manure



Source: Follet, Gupta, and Hunt 1987.

Table 1. Nutrients in Livestock Manure as Produced--Kilograms of Nutrient N, P_2O_5, and K_2O Per Animal Per Year

Animal	*Weight*	*N*	*P_2O_5*	*K_2O*
Dairy cattle	450.0	68.00	28.00	54.00
Beef cattle	450.0	56.00	41.00	48.00
Finishing pig	70.0	11.00	8.60	8.60
Poultry				
Layers	1.8	0.48	0.42	0.25
Broilers	0.9	0.39	0.20	0.14

Note: Livestock waste may be more valuable as a feed than as a source of plant nutrients.
Source: Livestock Waste Facilities Handbook 2.2. Second edition 1985, Midwest Plan Service, Iowa State University.

Here a point may be made that farm-level management of crop residues from high-yielding crops costs money, whereas in the low-yielding systems of the developing countries, crop residues are needed for fuel, building materials, animal litter, and so on, and have a market value. The high-yielding fertilizer using farms are therefore returning very large amounts of organic matter and plant nutrients to the soil in situ, whereas those farms that most need to return organic matter and maintain plant nutrient levels are removing everything but the stubble and roots and thus depleting both the organic and inorganic status of their soils. Simply stated the sustainability of yields is more assured under intensive agricultural systems than under subsistence or marginal farming.

Although increased environmental pressures are ensuring a greatly improved use of organic manures, the universities and research institutes have always had sound guidelines on their correct use. The private sector plays an important role in the design of storage, transport, and field application equipment. A particularly vocal private sector also ensures that the role of organic matter management in farming is not underestimated.

Maintenance of Soil Physical Properties

Historically, maintaining the soil's physical properties has been of prime concern for the farmer, and the timing of tillage operations to match optimum soil moisture contents for good results is a skill all farmers have to learn. Organic manures and correct crop residue management and rotations all improve soil physical structure.

Various synthetic soil conditioners are being marketed for agricultural use; Krillium (Monsanto), a synthetic organic soil conditioner, was available in the 1950s. The improvement of soil physical conditions is essentially controlled by the farmer's skills and by the equipment manufacturer bringing in innovative developments such as the high flotation equipment to lessen soil compaction.

Avoidance or the Reduction of the Effects of Toxicities

The classic toxicity problems are the acid nature of many upland soils and the salinization of arid soils. In Europe and North America, acid soils are treated with various basic materials and, particularly, crushed limestone. Most national liming programs have been subsidized because farmers in the 1930s and 1940s were reluctant to spend money on liming. The increasing use of soil acidifying nitrogenous fertilizers has always concerned agronomists who have developed sound liming programs for most farm situations. It should be noted that attempts to develop the use of neutral or less acidifying fertilizers have been overtaken by the development of low-cost technologies for urea production. It is appropriate here to draw attention to the fact that soil acidification can be a serious problem even where nitrogenous fertilizers are not used. The acidification of ley pastures in Australia caused by the mineralization of biologically fixed nitrogen in the soil is well documented.

Private sector contractors are a major source of agricultural lime for farmers in the United States and Europe. These contractors have shown their usual ingenuity in developing transportation and distribution equipment for a profitable market. Unfortunately, in large areas of the tropics, acid and aluminum toxic soils occur far from any source of limestone. Fortunately, much progress is being made by the International Agricultural Research Centers (IARCs) in selecting and developing aluminum-resistant cultivars.

Salinization is often a result of the application of faulty irrigation technologies; again the private sector on all continents has the expertise and equipment (developed by the private sector) to prevent or reduce the adverse effects of salinity. These private sector operators have strong trade associations and federal and state support in technology development, thus ensuring that their practices are not only fully advertised but also technically sound.

Maintenance of Nutrients and Optimization of Their Supply to Crops

The Evolution of the Role of Fertilizers and Their Impact

The fertilizer industry began essentially in northern Europe during the industrial revolution--a revolution which saw the beginning of massive movements of a burgeoning population from the countryside to the cities and a consequent rapid growth in the market demand for food. The history of fertilizer use is therefore closely linked to the production of cereal crops, and to this date, wheat, rice, and maize account for most of the fertilizer consumed annually. Developments in the production technologies for these three crops have had an impact not only on the quantities of fertilizer used but also on the products used.

Before the advent of the high-yielding wheat and rice varieties and hybrid maize, the major sources of plant nutrients were legume crops and farm and domestic manures. With these farming systems, the major constraint on cereal production was the low levels of soil phosphate which, in turn, led to the early development of the commercial phosphatic fertilizer industry (1842) based on sulfuric acid and phosphate rock.

The exploitation of potash deposits in Germany (1860) followed, and potassium chloride (KCl) became an important fertilizer. Nitrogen thereafter became the key constraint to cereal production, particularly in northern Europe where the legume crops, although essential, represented a lost opportunity to grow a cereal crop. The advent of synthetic nitrogen fertilizers in the early twentieth century led to only a slow replacement of the traditional sources of nitrogen with nitrogenous fertilizers. This slow growth in demand was due to economic factors (high cost of nitrogenous fertilizers and low cereal prices) and to the genetically unimproved nature of the cereal varieties used. At this stage of agricultural development, crop varieties available to farmers were not high-yielding and the bane of farmers around the world trying to grow higher yields of cereals was crop lodging, an affliction particularly associated with high fertility soils. For this reason, the emphasis in fertilizer use was on phosphate and potash with nitrogen being used only sparingly compared with today's practices. Under these conditions, the use of a 1:1:1 ($N:P_2O_5:K_2O$) nutrient ratio was, and still is, a widely accepted practice.

Because the key crops (wheat and rice) were self-pollinating, a wide range of distinct varieties existed. The challenge, therefore, was to use the various characteristics of the different varieties to produce crops that did not lodge and that therefore could respond in terms of higher yields to higher levels of soil fertility. Breakthroughs occurred over a very short period, and yields of rice in Japan and of wheat in the United Kingdom soared.

In the United States, the major crop with the potential for rapid intensification was maize, an open-pollinated crop; it was not until the introduction of hybrid maize that yields and consequently the demand for fertilizer grew. There was a long delay in the adoption of maize hybrid technology, which was discovered in the 1930s, a period of low prices, and which took off only in the 1940s.

With the advent of cheap synthetic nitrogenous fertilizer, the world pattern of nutrient consumption changed dramatically (figure 2). Much of the rapid increase in nitrogen used was due not only to varietal changes but also to changes in cropping systems (Parish 1987). A rapid increase in nitrogen use in the United Kingdom after 1950 was mainly a result of the replacement of ley farming systems, in which clover provided the nitrogen, with all-grass pastures that responded well to nitrogenous fertilizers. In the United States the maize-leguminous crop rotation was replaced by maize monocropping and nitrogen fertilizer use increased rapidly.

The impact of the increase in world fertilizer consumption has been enormous, and without this increased use the world would have faced unprecedented levels of malnourishment and famine. The goal of sustainable agricultural growth will become a bitter irony if the use of fertilizer is reduced in an irrational fashion.

The Major Fertilizer Products

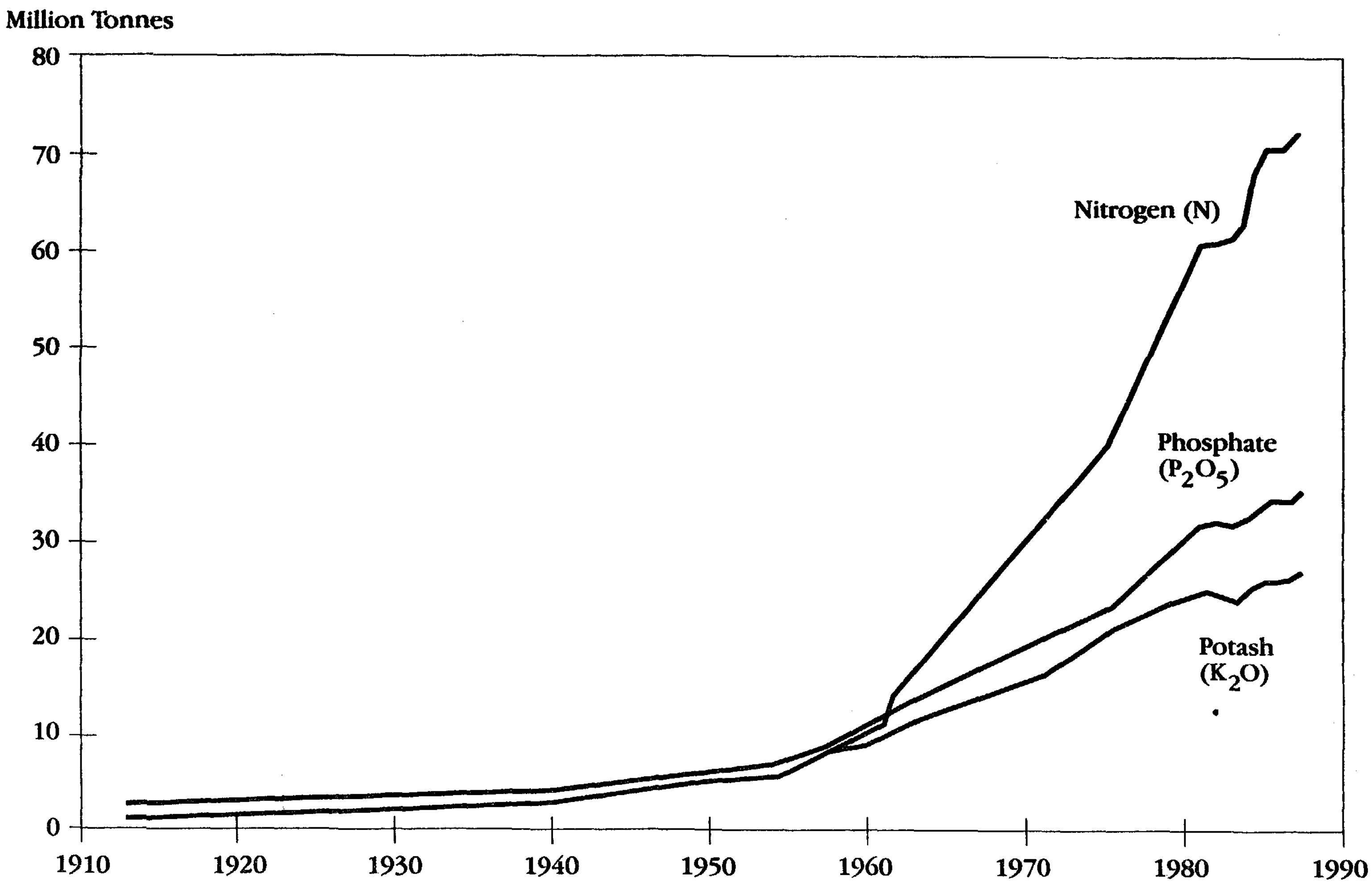
Nitrogenous Fertilizers. The Haber ammonia process developed by Germany before World War I is the basis of the modern synthetic nitrogen fertilizer industry. Neutralization of ammonia with acids yields ammonium sulfate, ammonium chloride, and various ammonium phosphates that became, and still are, important fertilizers.

Ammonium nitrate production developed initially because of the need for explosives, but it became and has remained a major fertilizer commanding premium prices on the world market.

Synthetic urea has been known for many years, but the lack of suitable technology constrained its production on an industrial scale; now however, it is the world's leading nitrogenous fertilizer.

Phosphate Fertilizers. Internationally traded phosphate (P) fertilizers are ground phosphate rock (PR), monoammonium phosphate (MAP), diammonium phosphate (DAP), the whole range of NPK

Figure 2. Nutrient Consumption in World, 1913-87



materials, triple superphosphate (TSP), single superphosphate (SSP), and ammonium phosphate/sulfate. Many countries must import all of their P needs; under these conditions the economic argument for high-analysis material, as with N fertilizers, outweighs the opportunity for some flexibility in the selection of imported P products.

SSP--SSP was, by far, the most important P fertilizer for over 100 years and is still an important fertilizer. It can be produced by uncomplicated processes and equipment, and its effectiveness as a source of P is unquestioned. Also it contains calcium and sulfur, which may contribute to soil fertility, and sometimes trace elements originating from the PR. Its main disadvantage is its low analysis, about 16 to 22 percent P_2O_5. Because of its low analysis it is usually made in small plants located in the market area. SSP (or partially acidulated phosphate rock) may be a good choice for developing countries (and for some developed countries) that have either sulfuric acid or PR or both. This is especially true when both P and sulfur are needed for good crop growth, which is the case in many parts of the world.

TSP, MAP, and DAP--Based on phosphoric acid, these products are essentially sources of water-soluble phosphate and are therefore agronomically equivalent; their popularity over SSP is due to their lower costs per unit of P delivered at the farm. DAP is now the most important P fertilizer.

Nitrophosphates--These products, which mainly use European production technologies, are based on nitric acid. They vary in composition and in the water solubility of the P they contain. Again, cost per unit of agronomically effective P delivered at the farm should be the basis for selection.

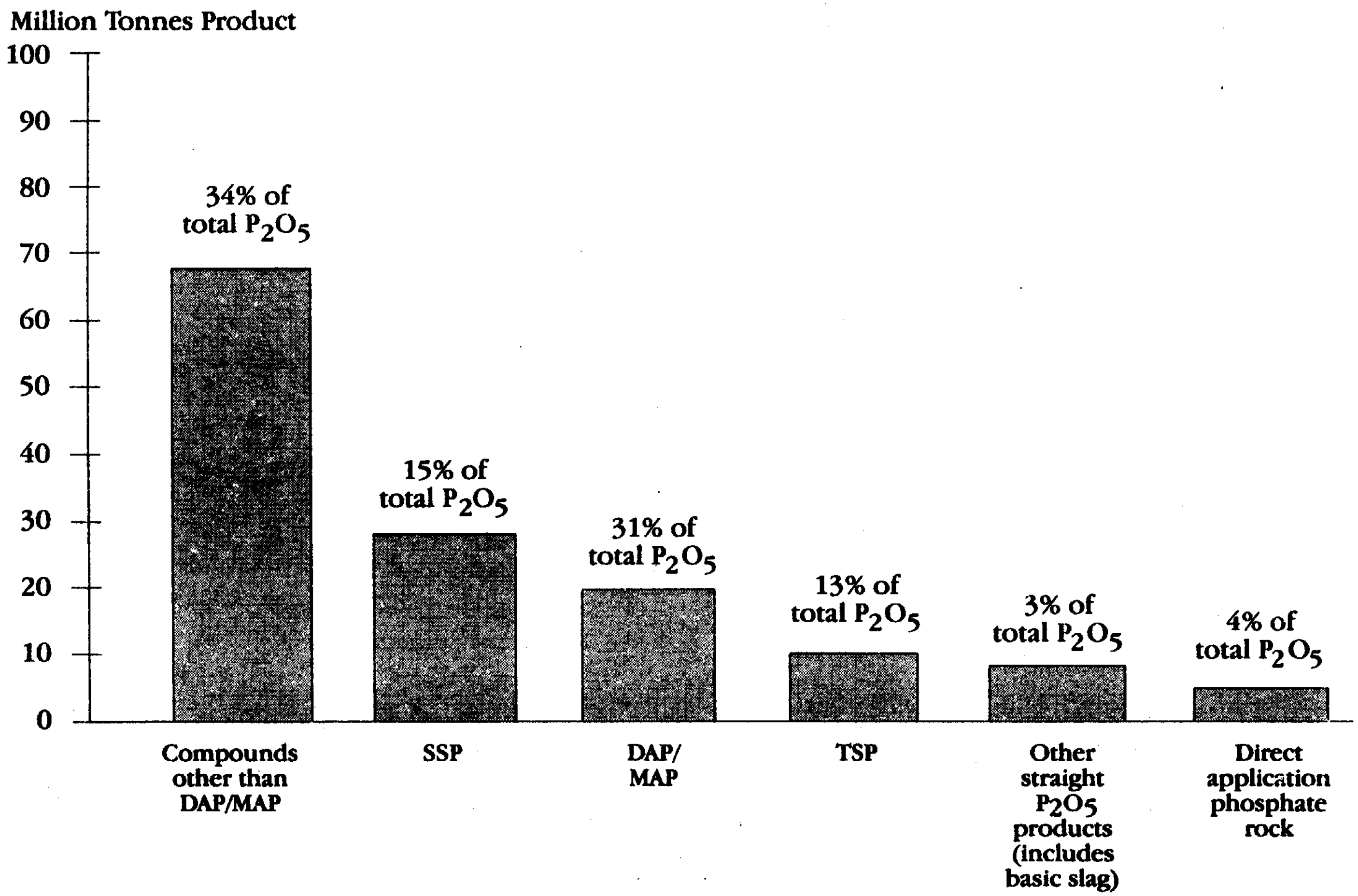
Phosphate Rock--In some situations, direct application of finely ground PR may be the least expensive way to supply P to crops. The practice is well established in several developed and developing countries, and it is estimated that directly applied PR accounts for 4 percent of the global use of phosphate (figure 3).

Potassium Fertilizers. Potassium chloride is the standard potash fertilizer. It contains the equivalent of 60 percent K_2O and thus is a concentrated source of potash. Because of the low cost of production, potassium is the cheapest commercially available nutrient and is simple to use. The current products used in the world market are shown in figure 3 (phosphate) and figure 4 (nitrogen) and the global product mix is shown in figure 5.

The main historical trend in product development has been the production of high-analysis fertilizers in order to reduce transport and storage costs, which can double the ex-factory costs of the product. The various NP and NPK products on the world markets fall into the high-analysis category.

There are many minor forms of fertilizers produced to use locally available byproducts or to meet a special local demand, and these often compete successfully in the marketplace. Significant quantities of organic fertilizers also are produced using industrial and urban waste. Japan, for example, has laws and incentives to cause industries to separate and process their waste into useful organic fertilizers. Wastes from seafood, animal, and oil seed processing industries, bark and waste wood from the lumber industry, and waste products from the synthetic fiber industry are all collected (often a disposal fee is paid by the producer of waste to the processor) and processed into organic/inorganic compound fertilizers. Today Japan produces over 1 million tonnes of organic fertilizer and more than 3 million tonnes of organic/inorganic fertilizers containing at least 15 percent of their nutrients in the organic form. These organic fertilizers are sold at premium prices in Japan to vegetable and fruit growers, ornamental specialists, and growers of other high-value crops.

Figure 3. Approximate Distribution of World Phosphate Consumption by Product

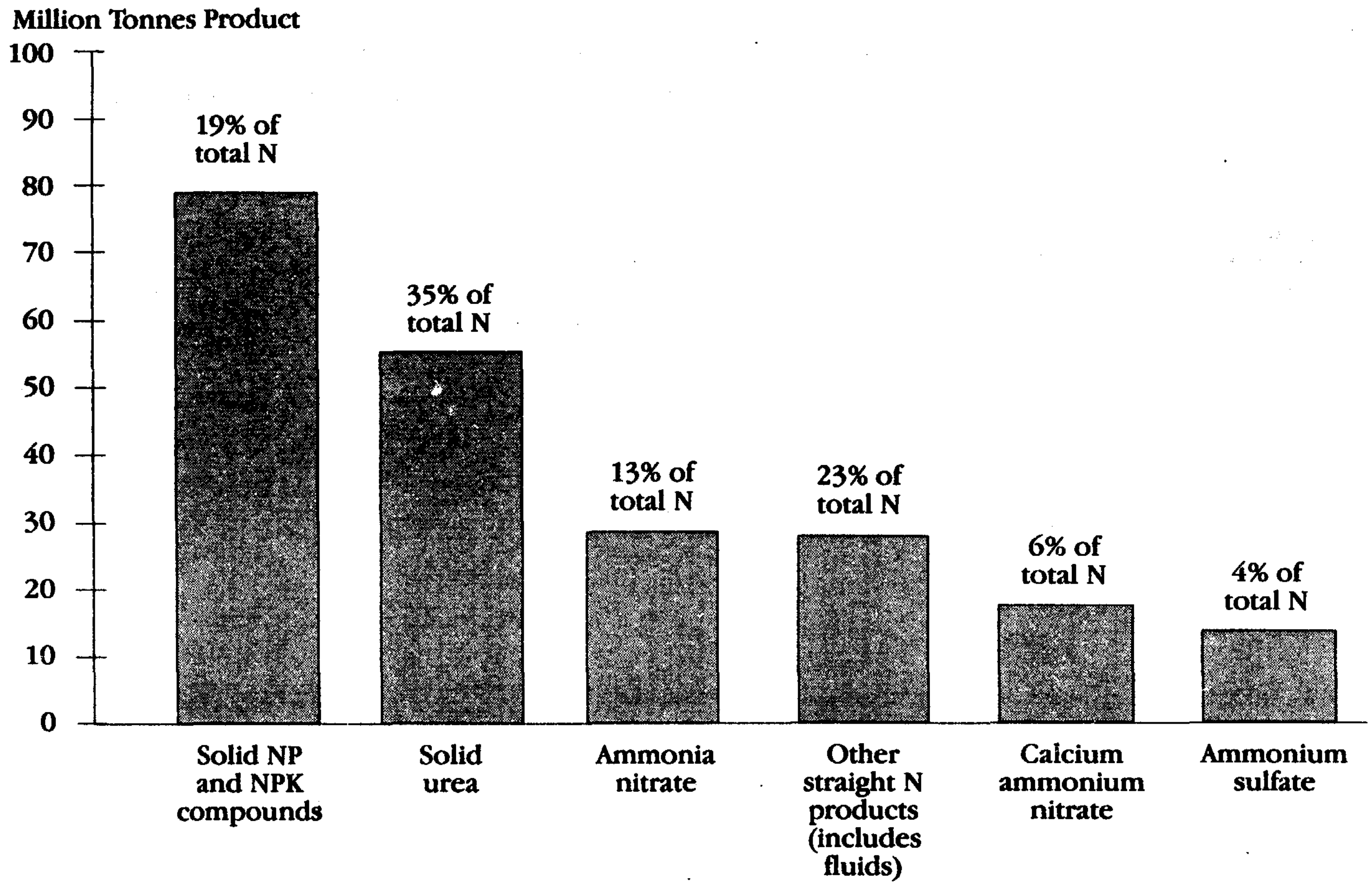


Total P_2O_5 consumption in 1985-86 was 33.0 million tonnes.

Total P_2O_5 consumption in 1985-86 was 37.8 million tonnes.

Source: Schultz (1990). Derived from phosphate fertilizer consumption data reported by the British Sulphur Corportation Limited (1987 and 1990).

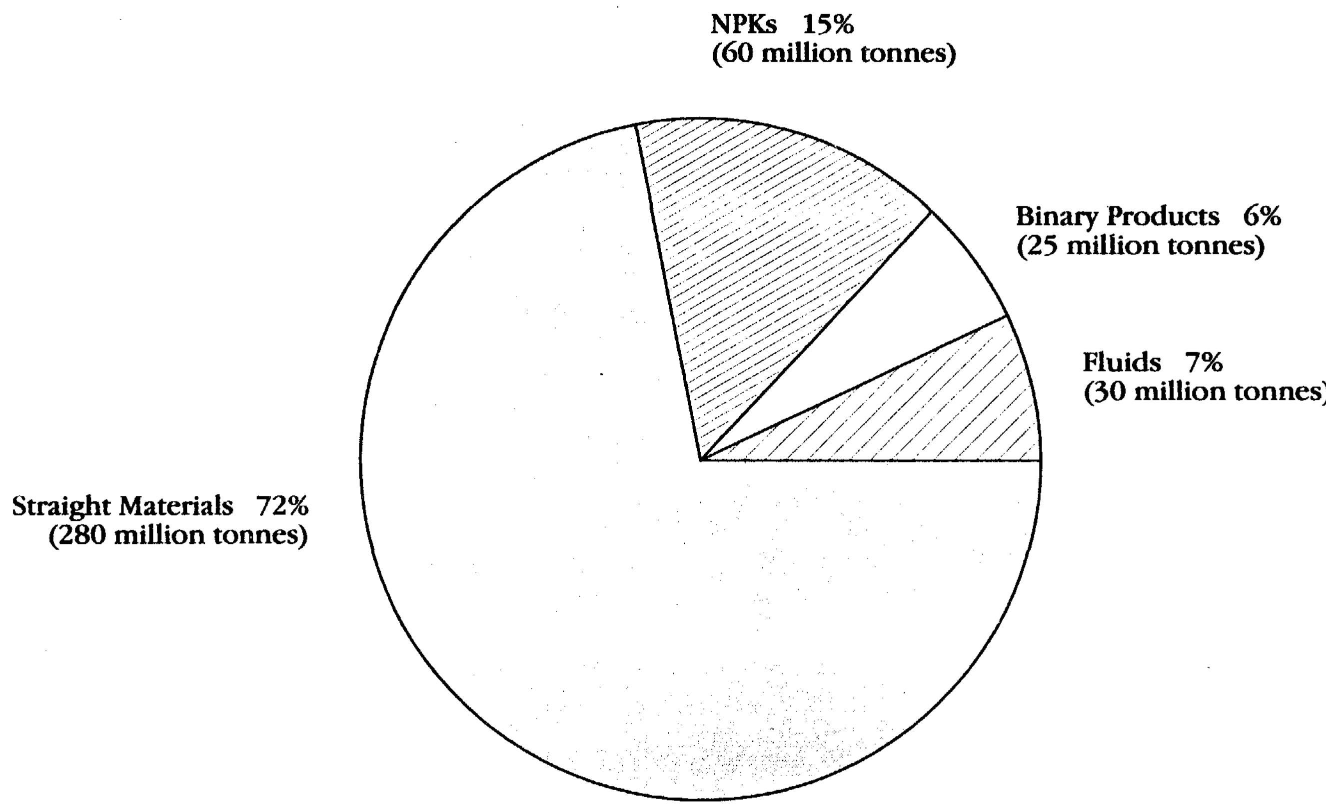
Figure 4. Approximate Distribution of World Nitrogen Consumption by Product



Total N consumption in 1985-86 was 70.3 million tonnes.
Total N consumption in 1988-89 was 79.0 million tonnes.

Source: Schultz (1990). Derived from nitrogen fertilizer consumption data reported by the British Sulphur Corportation Limited (1987 and 1990).

Figure 5. Estimated Current Annual World Fertilizer Production by Type (Product Basis)



Source: International Fertilizer Development Center (IFDC) 1990.

The fact remains, however, that the current pattern of industrial fertilizer production is such that innovation in the next 20 years is foreseeable only in the form that the fertilizers are delivered to the farmer. It is in this area that the United States has been a pioneer.

Tailoring Fertilizer Products to Meet Farmer Needs

With the low-yielding agriculture of the 1930s and 1940s, the widespread use of manures and legume crops and the lack of detailed knowledge of crop response compounded with farmer caution meant that fertilizer use developed only slowly and quite differently in different countries. Essentially, only cash crops were fertilized and fertilizer recommendations were of the simplest order--one bag of this or two bags of that.

Given a good soil supply of phosphate and potash, nitrogen is the key yield maker; its management is becoming increasingly critical. As a general rule, all the P_2O_5 and K_2O needed by a crop should be applied at or before planting, whereas applications of nitrogen should be made at times and rates defined by the climate, soil, and crop. Given this statement, the scope for the fertilizer industry to manufacture fertilizers exactly matched to soil and crop needs is limited, a fact which has influenced the development of fertilizer products in the form in which they are used by farmers. The current world production of fertilizers by major types given in figure 5 shows how important straight (single nutrient) fertilizers are.

The major requirement of the farmer is to have the fertilizer he needs available when he needs it, to reduce the expenses involved in storing and applying the fertilizer, and, not necessarily the most important, to have a good price. This is the basis of a competitive market. In many areas, however, such competitiveness has not developed because of governmental planning of the fertilizer market and the fact that production units are so large that the local unit often has a quasi monopoly. The United States provides an example of the impact of the private sector on the development of the fertilizer market. The changes and trends in U.S. product development described below are not universally applicable; nevertheless, with suitable modification they have had a major impact on many countries.

<u>Granular Compounds (NPKs)</u>. In 1960 production of homogeneous granular NPKs was about 12 million tonnes and accounted for 52 percent of the U.S. fertilizer market. The compounds were produced by 280 small plants scattered across the fertilizer use areas.

In 1989 only thirty-seven NPK granulation plants were operating. These produced about 2.4 million tonnes out of a total U.S. consumption of 46 million tonnes of product. The remaining plants are essentially servicing areas with specialty crops. The NFERC/TVA research has helped the NPK compound industry considerably in terms of technological innovations and in product quality control.

<u>Dry Bulk Blends</u>. Dry bulk blends are produced by mixing together two or more dry fertilizer materials to obtain a mixture (blend) of the desired nutrients in a predetermined ratio and concentration. Again NFERC/TVA has been a major contributor to this technology. Fertilizers are mixed to any ratio of nutrients requested by the farmer. Costs are competitive with those of the NPK granulation plants because the major sources of phosphate, KCl, and ammonia were and still remain on the periphery of the United States while the major market for fertilizer in the Corn Belt is in the center of the country. Therefore, the cheapest way of supplying the farmers was to bring the N, P, and K products together in the use area and to produce dry blends; because of the flexibility of the

blending system, any analysis requested by the farmer could be met. This tailoring of analyses to meet farm-level demand was something that the less flexible granulation plants could not do.

It should be born in mind that the major nitrogen source of the U.S. farmer is anhydrous ammonia, the use of which has peaked, and, increasingly, the newer nitrogen solutions. Because these liquid nitrogen fertilizers are applied separately from the dry fertilizers, most bulk blends in the United States are low in nitrogen. Another feature of the U.S. market is that bulk blends are usually mixed and spread within a few hours. Bagged blends need special precautions in production and storage. Bulk-blend technology is spreading outside of the United States. Table 2 gives the estimated world production in 1988.

Table 2. Estimated World Production of Blended Fertilizers by Country

Country	*Estimated Annual Production (million tonnes)*
United States	9.0
Canada	3.0
Brazil	2.8
Ireland	1.0
United Kingdom	1.0
Central America/Caribbean (Total)	0.6
Japan	0.6
Others	2.0
Total	20.0

Source: International Fertilizer Development Center (IFDC).

Fluid Fertilizers. Two types of fluid compound fertilizers are recognized: Liquids, in which all ingredients are in solution, and suspensions, which are liquids containing solids that are held in suspension by an addition of a gelatinous material such as certain types of clay. Fluid fertilizers are not a new development; several references to production and use of liquid fertilizers in the early part of the nineteenth century are found in the literature. Fluids are attractive because of their flexibility in nutrient content and particularly because the even distribution of the nutrients or their precise placement is easier with liquids than with solids.

The principal materials for liquid compound fertilizers are urea or urea-ammonium nitrate (UAN) solution, ammonium ortho or polyphosphate, and potassium chloride. UAN solution usually is less expensive than solid nitrogen.

The fluid fertilizer market in the United States developed rapidly over the past 25 years, and again NFERC/TVA has carried out necessary research. Fluid fertilizers have attracted a lot of overseas attention, but the experience of one company in the United Kingdom showed them not to be competitive with mini-bulk delivered dry blends.

The U.S. Fertilizer Retail Industry

The most interesting fact about the U.S. retail trade is that it is composed of many small-scale businesses and cooperatives. The following information is taken from a survey by Hargett and Berry (1988), which showed that there were 43.8 percent privately owned bulk-blend operations, 51.7 percent cooperatives, and 4.5 percent corporations. The figures for fluid fertilizers were 80.1 percent, 12.4 percent, and 7.5 percent, respectively.

Compared with bulk-blend plants, the average annual throughput of fluid plants tends to be smaller. The mode for fluids is 1,000 tonnes and the mode for bulk blending is 1,669 tonnes; the median for fluids is 2,018 tonnes, and the median for bulk blends is 2,153 tonnes.

A basis for the economical operation of these plants is the ready availability on the U.S. market of a wide range of fertilizer products that vary in nutrient price. Careful selection of materials can be used to lower raw material costs. Research by NFERC/TVA has been very important in helping to reduce dealers' costs, and the agency has developed a computer program designed specifically for dealer use that shows the cheapest way to achieve a desired analyses product with the material available.

A total of 36.3 percent of the liquid fertilizer tonnage is custom applied, 31 percent by the dealer, and 5.3 percent by application contractors. As with the bulk blends, farmer application of liquid fertilizer is far greater than custom application by the dealer, although dealers provide the rental equipment for farmers to apply 32.2 percent of the fertilizer. The farmer applies 31.5 percent using his own equipment.

The percentage for custom-applied suspension fertilizer is higher than that for both bulk blends and liquids. Seventy-one percent of suspension mixes are custom applied, primarily by suspension dealers rather than by custom applicators. This percentage of dealer application is greater because suspensions generally require more sophisticated application equipment.

As with bulk blenders, an increasing percentage of fluid plants offer complementary services. Of liquid plants, 71 percent add herbicides, 48.6 percent add insecticides, 79.8 percent add micronutrients, and 21.2 percent add seeds to mixtures. Of suspension plants, 95.8 percent report adding herbicides, 56.3 percent add insecticides, 89.6 percent add micronutrients, and 39.6 percent supply seeds. A key point to note in the services offered is an apparent decrease in consultancy services offered and the importance of soil testing as a service.

Appendix 3 gives a summary of the USAID/BADC privatization effort in Bangladesh, which was based on the development of private sector wholesalers and retailers--a concept applied only reluctantly by the state-operated agencies involved.

The Role of Consultancy Services in the United States

Universally, it has routinely been accepted that the key moment to pass on information relevant to the use of a material is at the time of purchase of that material. Fertilizer dealers in the United States, through their trade associations or the supplier's support, are well briefed on products and their use and thus have played a key role in the education of all American farmers in correct fertilization techniques.

Fertilizer recommendations are based on soil analyses carried out by both the private sector and the universities and in an atmosphere which implies, even if it does not prove, that the best farmers always use more fertilizer than the recommended doses. It would take a very brave or foolish salesperson in this atmosphere to recommend less fertilizer than his/her associates. The predilection of farmers for using more fertilizer than the county extension agent would normally recommend is not restricted to the United States. Table 3 shows, from the results of an actual survey, that U.K. farmers consistently use more fertilizer on key cash crops than is recommended by the extension service. Even in developing countries there are many examples of excessive fertilizer use.

Table 3. Recommended and Actual Nitrogen Fertilizer Application Rates in the United Kingdom

	Kilograms Nitrogen per Hectare	
	Actual (1984)	*Recommended (1985/86)*[a]
Winter wheat	187	200
Spring barley	98	100
Winter barley	150	100
Potatoes	214	160
Sugar beets	148	100
Oil seed rape	279	175

a. Given as examples only for crops growing under average conditions.
Source: Agricultural Development and Advisory Service (ADAS), United Kingdom.

Fertilizer has been used as a cure-all for crop production problems caused by disease and moisture deficiency, and it has been used particularly to correct the continual reduction in soil fertility caused by topsoil erosion and to expand production into marginal areas.

Blame always spreads faster than praise, and fertilizer is now suffering from a negative period in public esteem because of the increasing awareness of the danger of nitrate pollution of groundwater and the eutrophication of surface waters due to the runoff from fertilized fields. It is more important than ever, therefore, to ensure that the farmer receives the best advice available as regards his crop fertilization practices and that research to improve the efficiency of fertilizer use is intensified.

The private sector in the United States is very aggressive and resents any increase in government interference in their affairs. The recent move by the Agricultural Stabilization and Conservation Service to disqualify agronomists affiliated with fertilizer firms from assisting farmers on federal cost sharing programs has raised many hackles. A response by a major farm service organization makes the point that "we have been successful not because we sold someone a bill of goods but because we have worked hard to provide objective agronomic advice."

The growing impact of environmental issues pressures the fertilizer sector to use professionally qualified consultants. Fletcher (1991) states "While the form future programs will take is uncertain, it is already clear that NO_3 contamination from agricultural activities will not be immune to the increasing public demands for groundwater protection. Those who have traditionally answered the research and information needs of agricultural production must now take into account and address the impact of practices on groundwater, and they must work with their counterparts in the environmental agencies to design and implement programs that are compatible with the mutual goals of a sound agriculture and a sound environment." This statement clearly indicates the way that environmental concerns about nitrate contamination of groundwater will affect fertilizer use practices.

This concern, together with the increasing complexity of farm management operations, has already led to an increased farm-level demand for private consultants having recognized educational and experience levels. The American Society of Agronomy has, through the American Registry of Certified Professionals in Agronomy, Crop, and Soils (ARCPACS), given the necessary stimulus to the development of a formalized consultancy service; currently there are 505 ARCPACS registrants certified as Certified Professional Agronomists (CPAs). Of these, 213 CPAs work in industry, 77 in government, and 94 in universities, which is a good indication of the strength and role of the private sector in the pool of U.S. expertise in crop production-related areas.

With this background the USDA, through the Council on Soil Testing and Plant Analysis (CSTPA) based at the University of Georgia, is now developing a Soil and Plant Analysis Laboratory Registry, the objectives of which are as follows:

- To establish and maintain an accurate listing of those laboratories in the private and public sectors in the United States and Canada that are engaged in the analysis of soil, plant tissue, and water. The Registry will provide basic information for each participating laboratory.
- To list the analytical services provided by the laboratory and describe their capacity and capability.
- To identify the analytical resources available to assay soil, plant tissue, and water.
- To provide a means of technology transfer.
- To assist private and governmental agencies in obtaining information related to the fertility status of cropland soils and the impact of farming practices on the environment.

Soil testing and plant analyses are a major base of U.S. crop production technology, and the land grant universities have played a major role in developing the research and extension base. Beginning about 1960, however, commercial laboratories, often associated with fertilizer production units, greatly increased their activities in this area.

The Council is actively considering the following topics: (a) laboratory accreditation criteria, and (b) responses to proposed legislation concerning required soil and tissue analysis.

Environmental Concerns and the Opportunity for New Technologies

All crop cultivation practices including conservation tillage and the use of fertilizers and organic manures have beneficial effects that are accompanied by side effects in terms of nonpoint pollution. The Environmental Protection Agency (EPA) is very conscious of this fact and is preparing management guidelines that will affect farm practices (EPA 1991). The universities are increasing research and extension activities in the area of nonpoint pollution also. The major problem facing intensive agriculture today is reconciling profitability with sustainability and environmental protection.

Controlling eutrophication of surface waters due to runoff carrying highly fertilized soil and fertilizer from fields is a matter of rainfall and flood management combined with good timing and placement of fertilizers. This is a farm-level problem that good management and improved techniques can overcome. More serious for the whole agricultural industry is the public nervousness arising from nitrate pollution of the groundwater.

The manipulation of plant nutrient levels in the soil by using organic manures and fertilizers plays a key role in crop production, but the synchronization of these levels to match plant needs over the growing period has been and still remains a challenge. The best management practices widely publicized by the Phosphate and Potash Institute, particularly, will help, but the low efficiency of fertilizer nitrogen use (often less than 50 percent of N applied as fertilizer is taken up by the crop) will remain an opportunity for the research agronomist, the farm equipment supplier, and the chemical industry.

Coating of fertilizers, for example, the TVA sulfur-coated urea (SCU), has been developed. TVA's SCU performed remarkably well with flooded rice crops, and 60 kilograms of N as SCU equalled 90 kilograms of N from split applications of urea in yield performance (Martinez, Diamond, and Dhua 1983). To date, however, these fertilizers are so expensive that they have been used only for special purposes such as lawns.

The correct placement and timing of fertilizers will increasingly demand improved equipment to ensure efficient use of fertilizers. Maximizing efficiency of fertilizer use is an important step toward reducing any adverse environmental effects. Martinez, Diamond, and Dhua (1983) have shown that hand deep placement (10 centimeters below the soil surface) of large 1 gram to 3 gram particles of urea (supergranules) can improve the efficiency of urea N used by the flooded rice crop to the same degree that SCU does. The problem here is the difficulty in establishing the use of supergranules, which requires a linked village-level supply source and extension service system. Progress in Bangladesh in this area seems to be promising because it is based on small-scale production of the urea supergranules by village entrepreneurs who then sell directly to the farmers.

Because of the nitrate situation, the area with possibly the greatest development potential is that of nitrification inhibitors. Dow Chemical produced N-Serve in the 1950s, which found a use particularly in the Mississippi Delta cotton area where N-Serve was applied with anhydrous ammonia in the fall to help prevent nitrification of the ammonia and subsequent losses by leaching or denitrification. Up to 5,000 tons a year of the material was sold, however, it is no longer as widely used.

A new series of very powerful nitrification inhibitors has been or is being developed by the chemical industry; if these inhibitors become commercially available, they will give the farmer much more flexibility with his nitrogen fertilization programs.

Recent research has shown that controlling the ratio of ammonia to nitrate in a maize crop can lead to higher yields, and this technique has promise also (Bock 1987).

The improvement of production methodologies, distribution systems, and agronomic practices will maximize the benefits of fertilizer use while reducing any environmental impact the fertilizers may have. These improvements are very much needed.

Conclusions

Policy issues in fertilizer sector development are paramount and must be given top priority (Appendix 1); thereafter, the active role of any government in the fertilizer sector should be confined to major fertilizer production units, which if managed with private sector practices can be perfectly efficient. Additionally, and this is a very important point, government must establish a strong and enforceable legislation to control both the quality and quantity components of fertilizer sales. The farmer's confidence in his/her purchase is an essential component of all sound fertilizer marketing systems.

Large national primary fertilizer producers, whether controlled by the government or by the private sector, have functioned essentially as quasi monopolies supplying a fairly clearly delineated geographical zone. The efficiency with which they have been run has depended upon the degree of control that management has had in terms of development, raw material procurement, production planning, and most importantly, the degree of financial responsibility they have been allowed to assume. (It is of interest to recall that both ESSO and Shell were active in fertilizer production in the early 1970s, but that both later withdrew from this activity.)

At the farm level, the optimization and maintenance of soil fertility demands a well-integrated nutrient management program that must include a scientifically based fertilizer input program. Using the technical guidance that must come from a first-class research and extension base, the fertilizer producer and the wholesale and retail market operatives must cater to the needs of the farmer. It is in the latter areas--wholesale and retail marketing--that the private sector has played, and must increasingly play, a role.

For procurement, transport, and distribution, which together establish the delivered cost of the fertilizer to the farmer, the private sector, because of its flexibility and ingenuity, can outcompete successfully with any government system in terms of cost-effectiveness. It should be noted here that cost-effectiveness is not primarily a price factor because highly priced fertilizer available to the farmer as and when he needs it is more cost-effective than cheap fertilizer waiting for delivery from a warehouse.

Globally research on the need for and effective use of fertilizers is the responsibility of the national research institutes and universities, however, private sector funding of this research definitely supports and accelerates the flow of needed information.

State extension services are a tradition, but in the fertilizer field they have passed their zenith wherever a strong private sector exists. Increasingly, information, instruction, and monitoring activities initiated by the private sector have closed the links between the research worker and the farmer.

APPENDIX 1: NOTE BY DR. BALU L. BUMB, POLICY ECONOMIST, IFDC

Introduction

In assessing the role of the private sector in promoting nutrient management for soil fertility, crop production, and environmental protection, it is important to distinguish between what economists call public goods and private goods. Private goods are those commodities and services whose ownership are in private hands; whereas, public goods are those whose ownership and use cannot be controlled by a single individual or a group of individuals. Examples of such public goods are roads, highways, and irrigation canals. Likewise, education, research, and extension also fall in this category of public goods. Such goods lead to the problem of "free" riders--that is, the use of such goods by one does exclude the use by others. No private agency will therefore be interested in creating these goods because it cannot reap all the benefits of creating such goods. Hence, the creation and maintenance of such goods has to be done by the public sector or governmental agencies. On the other hand, private goods are easily tradable and therefore the private sector can take a lead in producing and marketing such goods. However, in such cases, the private sector will operate only in those areas where there is adequate incentive and profitability.

The Policy Environment

It was indicated above that the private sector participants will engage only in those activities that involve private goods and for which there are adequate incentives. However, the governmental agencies can play an important role in creating or retarding such incentives. For example, if fertilizer prices are controlled at a level that does not allow an adequate return on the invested capital and for risk taking, then the private sector will engage neither in marketing and distribution nor production and import of fertilizers. Likewise, control and tariffs will also discourage private sector participation. On the other hand, many developed countries have provided subsidies to protect domestic production of agricultural commodities. Such subsidies, if excessive, can lead to environmental damage by promoting excessive use of farm chemicals.

In other areas such as macroeconomic and trade policies, organizational and supply policies, and infrastructure and institutional development, the governmental policies and actions can have a profound impact on private sector participation. Hence, it is crucial that the developed and developing country governments should ensure that the prevailing policy environment is conducive for both private sector participation and long-term social development, especially in those areas where private profitability may result in counterproductive social development or environmental damage or both. A judicious combination of public sector support and private sector participation is essential for promoting efficient and environmentally sound nutrient management for sustaining soil fertility for crop production.

APPENDIX 2: CONSERVATION TILLAGE DEFINITION AND TYPES OF SYSTEMS

Conservation Tillage

Conservation tillage is any tillage and planting system that retains **at least 30 percent** residue cover on the soil surface after planting. Conservation tillage includes no-till or slot planting, ridge-till, strip-till, mulch-till (including stubble mulching), and other tillage and planting systems that meet the 30 percent surface residue requirement. Residue cover may be from meadow, winter cover crop, small grain, or row crops.

Types of Conservation Tillage

<u>No-Till or Slot Planting</u>. The soil is left undisturbed prior to planting. Planting is completed in a narrow seedbed approximately 1 inch to 3 inches wide. Weed control is accomplished primarily with herbicides.

<u>Ridge-Till (includes no-till on ridges)</u>. The soil is left undisturbed prior to planting. Approximately one-third of the soil surface is tilled at planting with sweeps or row cleaners. Planting is completed on ridges usually 4 inches to 6 inches higher than the row middles. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

<u>Strip-Till</u>. The soil is left undisturbed prior to planting. Approximately one-third of the soil surface is tilled at planting time. Tillage in the row may consist of rototillers, in-row chisels, row cleaners, and so on. Weed control is accomplished with a combination of herbicides and cultivation.

<u>Mulch-Till</u>. The total soil surface is disturbed by tillage prior to planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or blades are used. Weed control is accomplished with a combination of herbicides and cultivation.

<u>Reduced-Till</u>. Any other tillage and planting system not covered above that meets the 30 percent residue requirement.

APPENDIX 3: THE BANGLADESH STORY

Bangladesh was a people's democracy in which the role of the private sector in the fertilizer sector was officially nonexistent.

In the mid-1970s the government of Bangladesh (GOB) was encouraged to reform its public sector programs. In 1978 with U.S. Agency for International Development (USAID) assistance in the form of the Fertilizer Improvement Project, the GOB opened the retail trade to the private sector and eventually into national-level procurement and distribution.

IFDC was appointed by USAID and the Bangladesh Agricultural Development Corporation (BADC), a state monopoly trading in agricultural inputs, to be the consultants for the project with IFDC consultants being posted to Bangladesh in January 1978. The following report by Surjit S. Sidhu (1991), an IFDC economist attached to the project, gives a concise account of the history, problems, and achievements of the project.

During the past 13 years Bangladesh has made significant progress in reforming its fertilizer distribution and marketing system from a total public sector monopoly to a largely competitive free marketing system through a series of policy reforms. IFDC, through its Consultancy Services, has been along with the GOB and USAID a major participant in bringing about this transformation toward a market-oriented fertilizer marketing system. This paper briefly describes various developments that have taken place and are underway to bring about the desired change of building modern agriculture in Bangladesh.

There have been severe constraints for the diffusion of technological innovations in agriculture in Bangladesh, and only moderate success has so far been achieved.

The success has not been secular. It has been a crooked road with some reversals and switchbacks. In the process, however, some hard and valuable lessons have been learned:

- Changes in policy level personnel slow progress and often cause reversals of implemented policy.
- Sustainable success requires an extended period of time.
- At the time of project start-up, the only two types of businessmen in Bangladesh were very small bazaar-type dealers and patronage business houses (fifteen to twenty) who controlled, through informal cartels, almost everything. Thus, lack of a viable mid-level business community was a serious constraint. There was a need to develop a mid-level business infrastructure and help them become a dynamic competitive free market force. This obviously required time.
- Hasty attempts to privatize the system would have resulted in turning the fertilizer marketing business over to the cartel businesses already in place, which would have been counterproductive to the development of a competitive free-market system.

As we expected, strong resistance to the policy reform objective was quick to mobilize both within the parastatal and with many government agencies.

The method of implementation has been:

- A step-by-step approach. Project papers identified the overall objective only in general terms.
- Substantial input of management and marketing assistance.
- Development of an intensive Management Information System (MIS) to monitor and evaluate results of each step and to recommend the next step in detail.

- Substantial crop production technology assistance to distributors and their customers.
- Carefully planned and very intensive effort for the training and development of fertilizer dealers.
- A substantial commercial credit facility for the private sector fertilizer business for the transfer of distribution and marketing functions from the public to the private sector.
- Incentives to the government in the form of substantial grant funds, that is, (a) US$265 million for warehouse construction; (b) US$52 million for commercial credit; and (c) US$20 million for education and training primarily in the United States.

The sequence of steps involved in the approach for technical assistance were:

- Persuade the Government to allow the dealers to buy from any sales center and sell anywhere within the country. A Technical Assistance Team made extensive field visits and encouraged dealers to move to other sales centers when the one nearest was short of supply. Some started, others followed quickly. The MIS identified the benefits.
- Close 310 Thana Supply Centres (TSCs) while expanding the capacity of the remaining 110 using USAID grant funds. Increase minimum purchase criteria. Formalize Dealer Development Training in competitive marketing techniques. Constant MIS continues to identify benefits.
- Discontinue controlled farm-level price. Allow the dealers to sell at whatever price the market would bear. This step was recommended only when we were sure dealers had a grasp of and had experienced the benefits of competition. MIS continues in place. Results of this step improved availability with almost no change in farmer price, even though decontrolled.
- Open Thana Distribution Points (TDPs) at six key low transport cost sales centers. Give a quantity related transportation discount while continuing to intensify market development activity and working closely with dealers who showed promise and the ambition to expand their network. Constant MIS identified the benefits and fertilizer availability. Lower farmer prices and technology transfer from larger distributors to farmers had started. Thus we developed an adequate number of private sector distributors with background and experience in competitive free market concepts.
- Open direct purchasing from the local fertilizer factories at the same price as the parastatal charges with a 300-tonne minimum purchase. Continue technical assistance with direct purchase distributors. Continue MIS. This results in a (a) ultimate consumer price level dropped an average of TK 600/tonne x 1.5 million tonnes equal to US$26.47 million; (b) cost reduction to government equals about US$12 million (transport savings); (c) fertilizer use increased 25 percent compared to a previous 5-year average of 9 percent; and (d) record Aman harvest up 20 percent over the previous best year.
- Private sector import and elimination of all fertilizer subsidies.
- Institutionalize.

Endnotes

Traditionally, soil scientists have defined soil fertility on the basis of plant nutrient levels in the soil (Brady 1984). Young (1990) takes a much broader view, which incorporates the more recent thinking on the need for a sustainable agriculture. He, therefore, defines sustainable land use as that which achieves production while conserving the resources on which that production depends, recognizing, however, that the most direct and primary requirement for sustainability is to maintain soil fertility. Young then argues the following.

Soil conservation equals maintenance of soil fertility which requires:

- Control of erosion
- Maintenance of organic matter
- Maintenance of soil physical properties
- Maintenance of nutrients
- Avoidance of toxicities.

This approach widens conventional definitions even further.

In accepting Young's approach and including the environmental impact of fertilizer, it is probably necessary to change "maintenance of nutrients" to "optimization of the supply of nutrients to crops in terms of agronomic, economic, and environmental needs" and "avoidance of toxicities" to "the reduction or elimination of toxicities using plant breeding and soil manipulation techniques." These are the definitions used in this text.

Fertilizers traditionally have been defined as any organic or inorganic material of natural or synthetic origin added to a soil to supply certain elements essential to the growth of plants (Brady 1984). With this broad definition it is usual to refer to the commercial fertilizer products of industry as "fertilizer" and the remainder as organic fertilizers. For the purist urea is an industrially produced organic material; in practice, however, urea is classified along with ammonium nitrate, anhydrous ammonia, and so on, as a fertilizer.

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