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Training

- During 1986, 467 fertilizer sector personnel from 50 countries received training during 38 general and specialized programs in production, marketing, and use. New programs were offered in fertilizer quality control, fertilizer process economics, and fluid fertilizers. The Center helped organize and conduct three workshops. One workshop conducted at Headquarters concentrated on African fertilizer sector development; another held in China focused on the identification of ways to improve soil fertility and fertilizer efficiency on upland soils in the tropics and subtropics; and the third workshop conducted in Malaysia centered on crop modeling.
- During the past 10 years, the Center has trained at Headquarters and regionally over 3,000 people from more than 100 countries.

Technical Assistance

- During 1986 some 20 major technical assistance projects were conducted; this is twice the number for the previous year.
- Fertilizer sector studies were conducted for Cameroon and the Philippines.
- Marketing development studies were carried out in Kenya and Nigeria.
- IFDC participated in an Asian Development Bank mission to appraise various fertilizer issues related to an agricultural inputs loan to Pakistan.
- In Sri Lanka an IFDC economist and fertilizer technologist participated in an Asian Development Bank mission that developed the technical components of a fertilizer loan to that country.
- Latin American fertilizer companies benefited from IFDC technical assistance; two of these projects involved reduction in pollution control and the production of fluid fertilizers.
- A World Bank mission, headed by an IFDC distribution specialist, developed a 10-year fertilizer distribution plan for Indonesia.

National Programs

Bangladesh—IFDC assisted in the continued deregulation and privatization of the fertilizer distribution system. Between 1978/79 and 1984/85, the fertilizer subsidy was reduced from about 10% of the development budget to [illegible]. The unit subsidy fell from 50% of cost to 17%. Yet, despite this, fertilizer sales continued to grow by more than 10% per year. Fertilizer consumption per hectare has almost doubled during the past 10 years. During the past 7 years, rice production has increased from [illegible] million tons to 16.2 million tons. Crop diversification is gaining in popularity; fertilizer use on wheat, potato, mustard, sugarcane, and winter vegetables is expanding. Also, during the 7-year period, the share of the private sector in retailing rose to 90% of fertilizer sold.

Colombia—Research conducted in the Latin American phosphate rock network has provided considerable information on the agronomic performance of Colombian phosphate rock and products made from those rocks. In 1986 studies were conducted to evaluate the potential role of these products in the Colombian fertilizer market based on present and projected production capacity as compared to demand for conventional phosphate fertilizer. Data indicate a strong potential for these local resources to reduce the importation of phosphate rocks required to fill the gap between supply and demand for phosphate in Colombia.

Indonesia—To offset and relieve economic pressures, created by such items as fertilizer subsidies, the Government of Indonesia placed a greater emphasis on improving fertilizer efficiency of upland crops and broadened the program to include industrial crops. During 1986 a working group was established to improve fertilizer efficiency in industrial crops such as sugarcane, oil palm, and rubber. The increased export of these crops should provide a major source of foreign exchange for the Indonesian economy.

Mali—Based on results of IFDC's phosphate project in Mali, the Government of Mali has strongly encouraged the extension services to use local Tilemsi phosphate rock for direct application. They also encouraged these extension services to use IFDC's farm-level testing approach for demonstration.

Highlights of 1986

During 1986 the International Fertilizer Development Center (IFDC) conducted its various activities involving research, technical assistance, training, and national programs in a total of 35 countries—16 in Africa, 10 in Asia, and 9 in Latin America.

Regional Center

Plans progressed for IFDC's African connection. The Togolese Government provided the land to build the IFDC-Africa Headquarters. Initial program support was pledged by the United Nations Development Programme, International Development Research Centre, the World Bank, Rockefeller Foundation, and the Dutch Government. According to an African national, this new institute "will help farmers place more food on their tables and help to create a better way of life for their children."

Evaluation Mission

An evaluation mission of the United Nations Development Programme assessed the progress of an IFDC global project on research and training in fertilizer technology and use. The mission emphasized "its respect for the high quality and worldwide importance of the research and training activities conducted by IFDC." The report called for a "continuation and even an increase of the support...(that the Mission) is certain will lead to the extended and more efficient use of fertilizers, and, therefore, to increased food production in developing countries."

Research

- IFDC's Africa research network involved scientists in Burkina Faso, Cameroon, Gambia, Ghana, Côte d'Ivoire, Liberia, Malawi, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo, and Zambia in a cooperative effort to find ways of economically using N, P, K, and S fertilizers in general and more specifically of using indigenous materials for phosphate fertilizers.
- IFDC completed 6 years of nitrogen efficiency research in semiarid tropical India. Results dispelled the past fears associated with fertilizer use in these ecologically disadvantaged regions. Findings from this research established a remarkable potential for increasing crop yields through nitrogen fertilization across contrasting rainfall environments, provided soil depth was not shallow (<50 cm). It was shown that it was only with shallow soils that fertilizer N use efficiency was low and losses of nitrogen were high. Future efforts will be directed to identify the mechanisms of nitrogen loss and find out ways to prevent this.
- A phosphate network, involving Bolivia, Colombia, Costa Rica, Ecuador, Mexico, Peru, and Venezuela, was developed. Four of these countries sent sample materials from their phosphate deposits to IFDC; test fertilizers were produced using these indigenous materials. The primary objective of the network is to find methods of improving the agronomic efficiency of these phosphate rocks in highland cropping systems. Results indicate that partial acidulation of the rock with sulfuric acid significantly improves crop response under these conditions. Network tests have also provided information on the identification of the most effective management procedures for unacidulated phosphate rock, but partially acidulated phosphate rock continues to be superior to unacidulated phosphate rock for the highland cropping systems.
- A coordinated study between the Fertilizer Technology and Agro-Economic Divisions resulted in the identification of a process for producing fertilizer using phosphate rock from the Mussoorie deposit; the Indian nationals have prepared, with IFDC assistance, the design for the first partially acidulated phosphate rock fertilizer plant in India.
- A joint patent on urease inhibitors was acquired by IFDC and the National Fertilizer Development Center of the Tennessee Valley Authority.

Awards

- Four awards were presented to IFDC's staff and Board of Directors during 1986. Chairman of the Board Dr. John A. Hannah received the Lifetime Achievement Award—one of the Fourth Annual Presidential End Hunger Awards.
- Managing Director Dr. Donald L. McCune received a U.S. Public Service Award from the American Society for Public Administration and the National Academy of Public Administration.
- In recognition of a lifetime of outstanding service and technical contributions to the fertilizer industry, farmers, and people of the world, Mr. Travis P. Hignett, Special Consultant to the Managing Director, received the Outstanding Service Award from the Fertilizer Industry Round Table.
- Dr. Dennis H. Parish, Director of the Outreach Division, received a commemorative medal from the Food and Agriculture Organization of the United Nations for his work as Regional Leader for Africa and Asia in the FAO Fertiliser Programme.

Publications

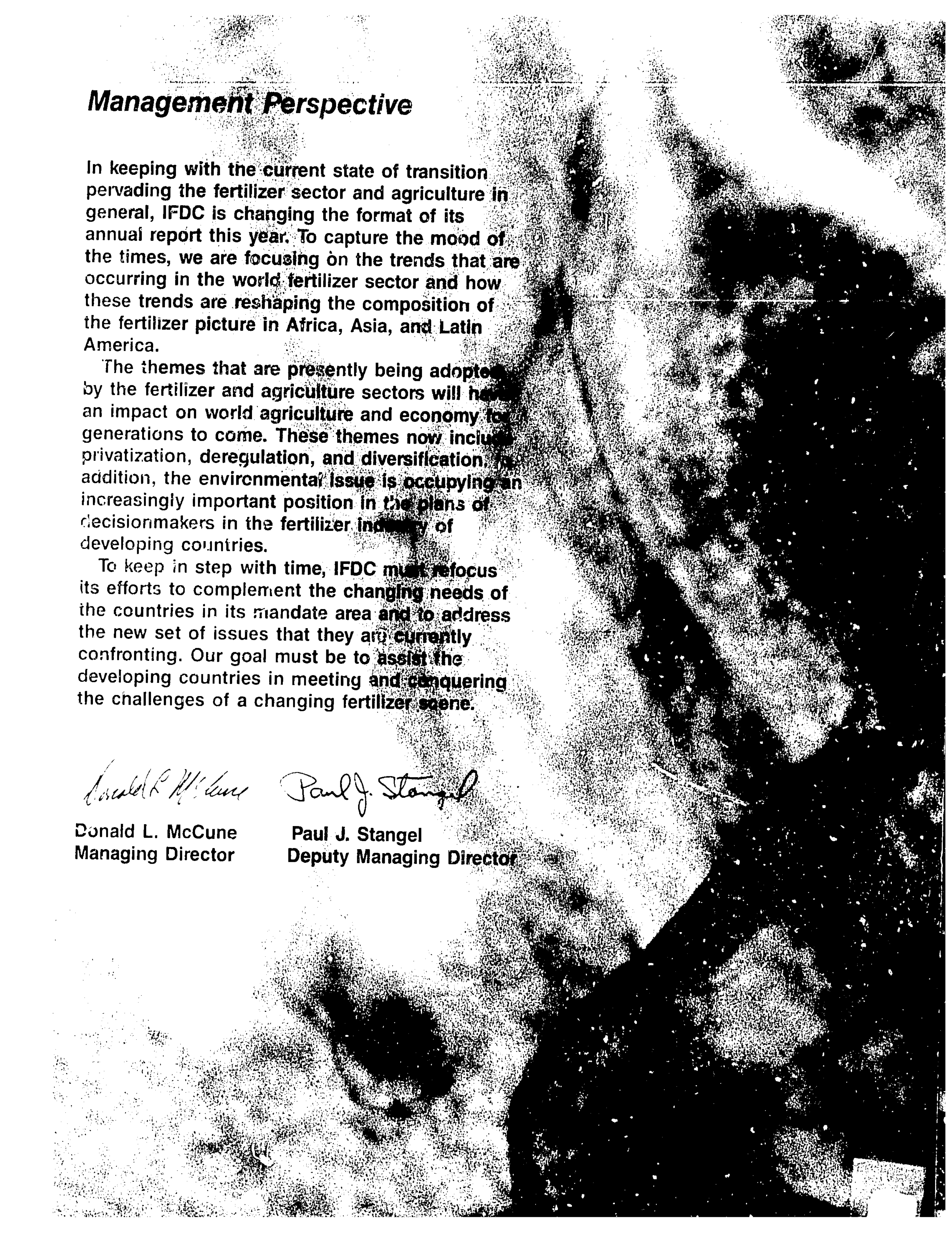
- Five major publications were released by IFDC during 1986. These publications included: *Fertilizer Sulfur and Food Production: Research and Policy Implications for Tropical Countries; Management of Nitrogen and Phosphorus Fertilizers in Sub-Saharan Africa; Proceedings of a Workshop on Urea Deep-Placement Technology; Sulfuric Acid-Based Partially Acidulated Phosphate Rock: Its Production, Cost, and Use;* and *A Manual for Determining the Physical Properties of Fertilizers.*
- In addition, approximately 40 manuscripts were published in various international agricultural research journals, proceedings, and other publications.

Staff Changes

- Dr. Paul L.G. Vlek, Director of the Agro-Economic Division for the past 3 years, was appointed Director of IFDC-Africa, based in Togo.
- The Agro-Economic Division received a new director; Dr. Lawrence L. Hammond, Soil Scientist, was promoted to lead that division.

New Board Members

The Board of Directors gained two new members during 1986. They are (1) Dr. Pieter van Burg, Director of the Netherlands Fertilizer Institute, and (2) President of MANAH S/A Fernando Penteado Cardoso of Brazil (reappointed after being off the Board for 3 years).



Management Perspective

In keeping with the current state of transition pervading the fertilizer sector and agriculture in general, IFDC is changing the format of its annual report this year. To capture the mood of the times, we are focusing on the trends that are occurring in the world fertilizer sector and how these trends are reshaping the composition of the fertilizer picture in Africa, Asia, and Latin America.

The themes that are presently being adopted by the fertilizer and agriculture sectors will have an impact on world agriculture and economy for generations to come. These themes now include privatization, deregulation, and diversification. In addition, the environmental issue is occupying an increasingly important position in the plans of decisionmakers in the fertilizer industry of developing countries.

To keep in step with time, IFDC must refocus its efforts to complement the changing needs of the countries in its mandate area and to address the new set of issues that they are currently confronting. Our goal must be to assist the developing countries in meeting and conquering the challenges of a changing fertilizer scene.

Donald L. McCune
Managing Director

Paul J. Stangel
Deputy Managing Director

Contents

On the cover:
Crossed nicols photomicrograph of apatite crystals in a chalcedony matrix of the Chilembwe phosphate rock deposit in Zambia. Photography by Tommy Wright and Steven J. Van Kauwenbergh. Cover designed by Jimmy Starkey.

Transport vessels in Bangladesh.

World agriculture, in general, and the world fertilizer sector, in particular, are in a state of transition. The sectors are moving from a preoccupation with increasing production of basic food crops to a more balanced and diversified approach that will lead to an improved diet, sustained self-sufficiency in food, and increased diversification of agricultural exports. A series of events over the past decade has altered the course of the fertilizer sector's development, particularly the points of production and consumption, and promise to continue to be influential on overall sector development for many years to come.

The political and economic events and activities that first triggered the sharp focus on food production and are now encouraging a more diversified agriculture have profoundly influenced the fertilizer sector during the past decade. The more significant of these are as follows:

1. The oil embargo of 1973/74 and subsequent tenfold increase in energy costs to 1979/80.
2. The food and fertilizer shortages of 1973/74.
3. The Lima Declaration of 1975, which made a commitment to move toward self-sufficiency in the fertilizer sector of developing nations.
4. The economic recession that gripped the world during the early 1980s and which in some countries has not yet abated.
5. Record crop production and low commodity prices since 1981.
6. The high degree of government intervention in many developing countries in both the fertilizer and agricultural sectors through government ownership of fertilizer facilities, subsidies, and price controls.

(Photo Above)
Having achieved self-sufficiency in many of the basic food crops, several developing countries are diversifying their agriculture and thereby providing a more balanced diet for their people. These Bangladesh workers are cultivating a vegetable crop.

Impact of Political and Economic Events on Agriculture

The impact of these events on world agriculture has been dramatic over the past decade. Production of food and fiber rose significantly, particularly in developing countries. For example, traditionally food-deficit countries like India, China, Indonesia, Pakistan, and Brazil are either self-sufficient or net exporters of one or more of the following: wheat, rice, maize, sugarcane, and cotton. Of greatest significance is the fact that growth in agricultural production surpassed population increases and directly benefited large segments of the world's population. For example, the recent report, entitled *Fifth World Food Survey*, by the Food and Agriculture Organization of the United Nations (FAO), has revealed that average annual growth rate in dietary energy supplies (DES) climbed sharply between 1961 and 1983. As a result, 75 of the 112 developing countries showed a DES growth rate greater than was their growth in population. In other words, food supplies available for their people were considerably higher and with proper economic policies would, on the average, improve their daily caloric intake to levels substantially higher than those of 15 years ago.

However, there is reason for concern. First, 26 countries, half of which are in Africa, showed a decline in per capita DES since 1973. Furthermore, growth in per capita DES for the world since 1979-81 has slowed and actually stagnated in Latin America and most developed countries.

This slowing of growth has been due to two factors. Lack of profitability to produce the basic crops of food and fiber is one of the factors. This has been aggravated by huge world surpluses, associated low international prices, and subsequent removal of fertilizer subsidies and/or price supports in more and more countries. A contributing factor to this slowing in world food production has been the drought and famine that has occurred periodically in much of Africa since 1973 and which was particularly severe in 1980-84.

As a result of the development of fertilizer-responsive, modern, high-yielding varieties and the use of other inputs, such as fertilizer, water, pesticides, and herbicides, world agriculture has huge surpluses of basic supplies of food and fiber; much of it exists in developing countries but is inaccessible to many because of economic and geographic constraints. Furthermore, the mix of much of these supplies is not of the right type to meet the changing demand of the portion of the world's population that has an increasing income. To solve this dilemma, agriculture must diversify its crop mix. It must do this by shifting its present policies now aimed at increasing production of rice, wheat, and maize and redirect this effort to crops where a particular country has a comparative advantage in exports or where growing domestic demand (particularly for oil crops, fruits, and vegetables) is left unsatisfied.

In either way, these shifts are resulting in a changing pattern of fertilizer use, causing a change in the form in which fertilizers are supplied and applied.

Changes in the Form and Price of Fertilizer Used

Great changes have occurred in the worldwide fertilizer industry during the past 20 years—both in the kinds of fertilizers produced and consumed, and in the location of the plants that produce them. Twenty years ago, the developing countries produced less than 5% and consumed less than 10% of the world's fertilizer. Today they produce 17% and consume 23% (Figure 1).

Nitrogen—The form in which nitrogen fertilizer is consumed has varied

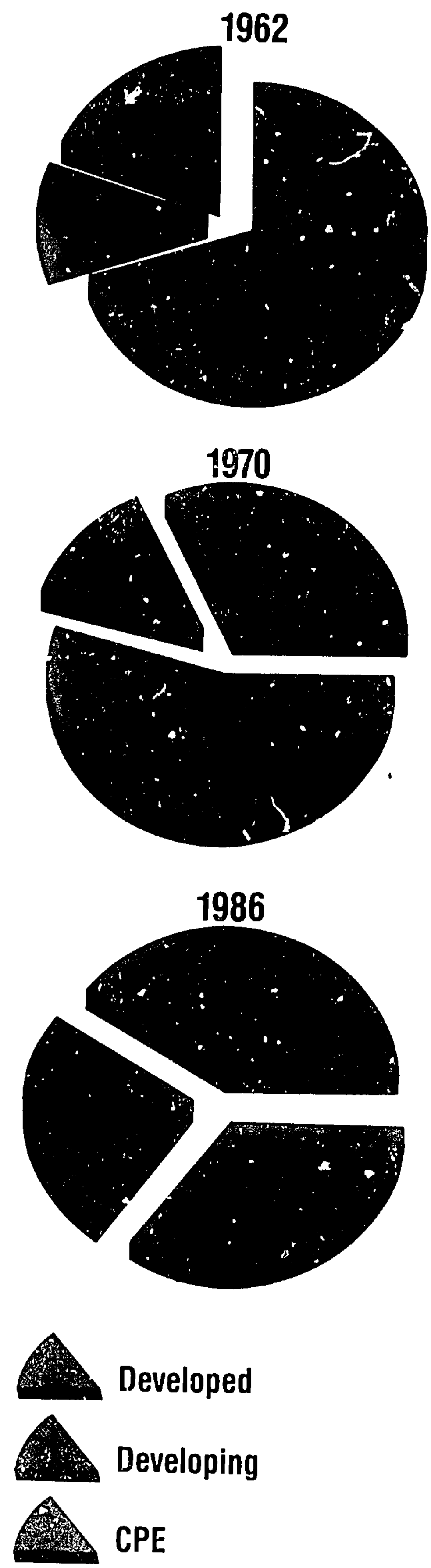


Figure 1. World Fertilizer Consumption.

markedly over the past 30 years. In the 1950s ammonium sulfate and ammonium nitrate were the dominant forms of nitrogen consumed. By the early 1980s, urea had assumed this position and today accounts for about one-third of the world total. Other important forms and their percent consumed are: ammonium nitrate 21%, compounds 18%, and ammonium sulfate 4%.

Phosphate—Similar patterns of change have emerged in the use of phosphate. Single superphosphate, the dominant form of phosphate in the 1950s, has been replaced by triple superphosphate, ammoniated phosphates, and compound fertilizers as the principal means by which farmers supply this nutrient to their crops. Most (60%) of the phosphates consumed in world agriculture are in the form of compounds. Single superphosphate (SSP) and double superphosphate are a distant second (18%), followed by triple superphosphate (14%), other straights (7%), and basic slag (1%).

Potassium—Most (57%) of the world's potash is applied directly as potassium chloride, followed closely by compounds (37%). Relatively small quantities are applied directly as potassium sulfate (2%), double salts of potassium and magnesium (1%), or in other forms (3%). This pattern is quite different from that of 20 years ago, when nearly 75% of all potash was applied directly as KCl and about 22% as compounds.

Prices—The prices of fertilizers have changed dramatically since the world food and fertilizer crisis of 1973/74. Nitrogen fertilizers, being more energy intensive than the others, have shown the greatest price fluctuations, with urea selling for less than $50/mt in 1971, approximately $400/mt in 1974, and less than $100/mt in 1986.

Effects on Production, Consumption, and Trade of Fertilizers

The impact that political and economic events and changes have had on the fertilizer sector during the past decade is reflected in the patterns of production, consumption, and trade of fertilizers on a global basis.

Production—World production of fertilizer nitrogen increased from 44.7 million mt of nitrogen in 1976 to 74.5 million mt of nitrogen in 1985 and then declined to 73.7 million mt of nitrogen in 1986. This represented an annual compound growth rate of 5.1% over the past decade.

Global production of phosphate fertilizer was 34.8 million mt (P_2O_5 basis) in 1986. This was up from the 25.1 million mt posted 10 years earlier and represents a growth rate of 3.3%/year.

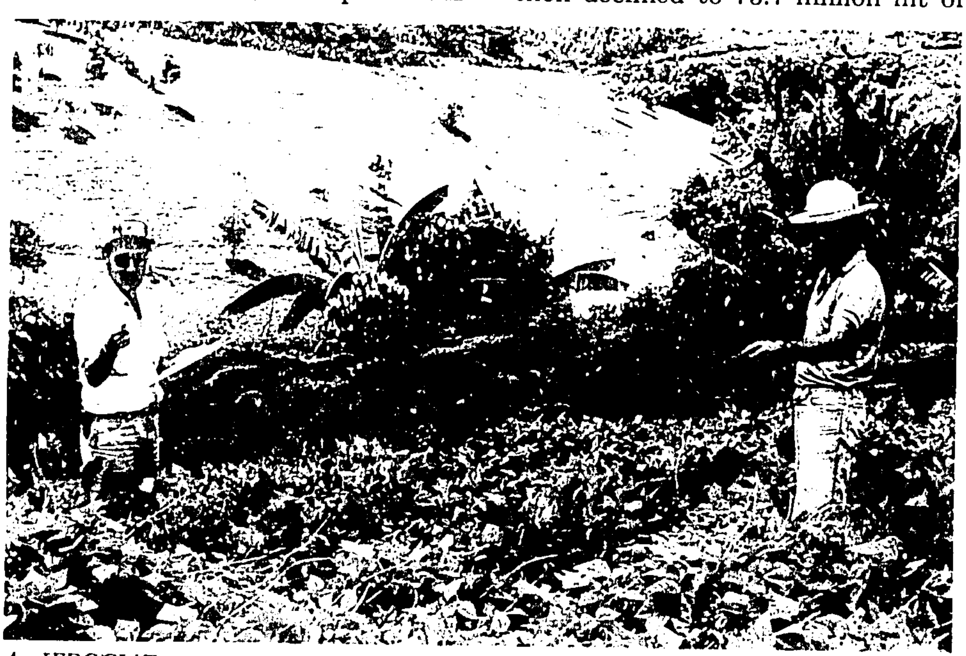
Potash fertilizer production also increased, climbing from 23.2 million mt (K_2O basis) in 1976 to 28.4 million mt for 1986. This represented a growth rate of 2%/year.

Consumption—Prior to 1974, fertilizer consumption had increased over the previous year consecutively since 1945. Since 1974 total fertilizer consumption has declined from the previous year on four occasions—1975, 1981, 1982, and 1986.

World consumption of nitrogen fertilizer benefited most by the events of the past decade. Total annual consumption, which in 1976 was 43.6 million mt of nitrogen, grew rapidly throughout the decade. Although world use of nitrogen stagnated temporarily in 1982 at 60.3 million mt because of a world recession, it made a strong recovery and reached 70.5 million mt in 1985. Nitrogen consumption in 1986 was estimated at slightly below 70 million mt. Average annual compound growth in nitrogen use was 4.9% for the 10-year period ended in 1986.

World phosphate fertilizer consumption, which in 1976 was 24.4 million mt of P_2O_5, grew at a rather unsteady rate during the decade before reaching 34.0 million mt in 1985 and then declined to 33.1 million mt in 1986. As a result of the fluctuations in P_2O_5 use, the compound growth rate for the 10-year period was only 3.1%/year. Total world phosphate use has actually declined over the previous year in 3 of the past 5 years.

Growth in potash fertilizer use over the past 10-year period was even more sluggish. Starting from a base of 21.3 million mt of K_2O in 1976, potash use reached 24.5 million mt in 1979 and then virtually stagnated, reaching only 25.6 million mt of K_2O in 1986. The average annual compound



An IFDC/CIAT research assistant and a Colombian farmer, collaborators on the Colombian-based phosphate project, evaluate bean varieties.

growth rate of potash use was 2.0% for the 10-year period.

Trade—World trade of fertilizers is of utmost importance to the fertilizer sector. In 1986 about 41 million mt of nitrogen, phosphate, and potash (nutrient basis) moved in international trade. This represents an increase of over 75% from the volume of fertilizers traded in 1976.

1. **Exports**—The U.S.S.R., United States, Netherlands, and Romania are the leading exporters of nitrogen. In 1986 these countries accounted for 45% of the 15.2 million mt of nitrogen exported. The U.S.S.R., relying on nitrogen exports as a source of foreign exchange, has increased nitrogen exports by fivefold during the past decade.

   The United States accounts for one-third of the world's exports of phosphate fertilizer (8.8 million mt of P_2O_5), followed by Tunisia, Belgium/Luxembourg, Morocco, and the Netherlands. These five countries accounted for over 50% of the phosphate fertilizer exports in 1986. Tunisia and the Republic of Korea became more important as phosphate exporters during the past decade, whereas Canada declined in importance.

   As might be expected, potash accounts for the highest tonnage (16.6 million mt of K_2O in 1986) of fertilizer moving in world trade. Canada is the largest potash exporter in the world, followed by the U.S.S.R., German Democratic Republic, Federal Republic of Germany, and Israel. These five countries accounted for 89% of the world's potash exports in 1986.

2. **Imports**—The United States is the world's leading importer of nitrogen and accounted for 22% of the total world imports in 1986. China ranks second in imports (2 million mt of nitrogen in 1986) and accounted for 12% of the world total in 1986. India is the third largest importer of nitrogen, accounting for 10% of the world total.

   China, India, and France were the largest phosphate-importing countries in 1986. These three countries accounted for 28% of the world's phosphate imports in 1986.

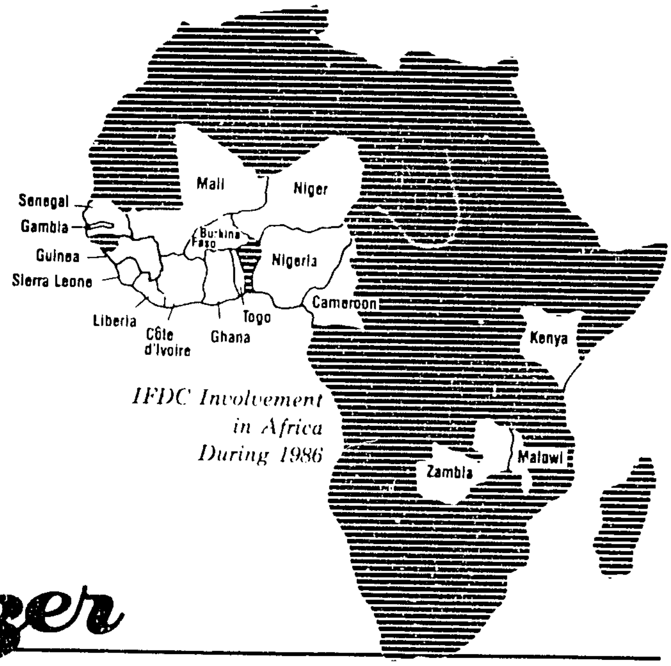
   The United States is the largest importer of potash, accounting for about one-fourth of the world's total. Poland, Brazil, France, and India complete the list of the top five potash-importing countries. The top five countries account for about one-half of the world's potash imports.

Note: The sources of data on the food and fertilizer situation for the world, Africa, Asia, and Latin America used in this publication include: FAO, the International Food Policy Research Institute (IFPRI), and the World Food Council. All 1986 data are preliminary.

Indonesian women sell fruit at a farmers' market.

Workers unload fertilizer from a barge in India.

The African Situation: Food and Fertilizer



IFDC Involvement in Africa During 1986

Declining Food Production

The agricultural sector dominates the economy of most of the countries of Africa. Food production increased approximately 1.9% per year between 1961 and 1980 in sub-Saharan Africa. Countering this progress is the nearly 3% per year increase in population over the same period, resulting in a decline of 1.1% in per capita food production.

Potential beneficiaries of the recently formed IFDC-Africa Division, based in their home country of Togo.

Food production languishes in part because many of the governments in Africa are reluctant to allocate or are incapable of allocating sufficient funds to the basic building blocks of agricultural development: agricultural research, agricultural extension services, rural infrastructure, and economic incentives. A broad-based agricultural development is crucial for increasing incomes, employment, and export earnings. Raising the incomes of the rural poor is essential for increasing government revenues and creating a domestic market for the goods and services produced in a rapidly growing urban sector. Availability of appropriate technical packages adapted to local conditions, timely supply of inputs, effective extension services, and reasonable pricing policies are all necessary elements for the revival of the ailing agricultural sector.

Sub-Saharan Africa consists of over 40 low-income tropical countries. Many of these countries are facing serious food, hunger, and nutrition problems. The food problem in sub-Saharan Africa is as serious today as it was in Asia in the 1960s, at least in the relative sense. According to the World Food Council, 25 of the 43 food-priority countries are in sub-Saharan Africa. The projected gross food deficits for 1990 in sub-Saharan Africa are estimated to be between 27 million tons and 34 million tons (cereal equivalent).

The only long-term solution to the food problem in sub-Saharan Africa is to increase domestic food production and decrease the population growth and urbanization rate. Needed growth in food production to meet the 1990 projected consumption target in sub-Saharan Africa is between 4.0% and 4.4%/year (more than double the growth rate registered during the past two decades), depending upon the income growth scenario.

The Status of the Fertilizer Sector

Fertilizer use, along with other complementary agricultural inputs, is expected to play a vital role in transforming traditional agriculture and accelerating agricultural growth in Africa. In fact, it is generally accepted that of the total

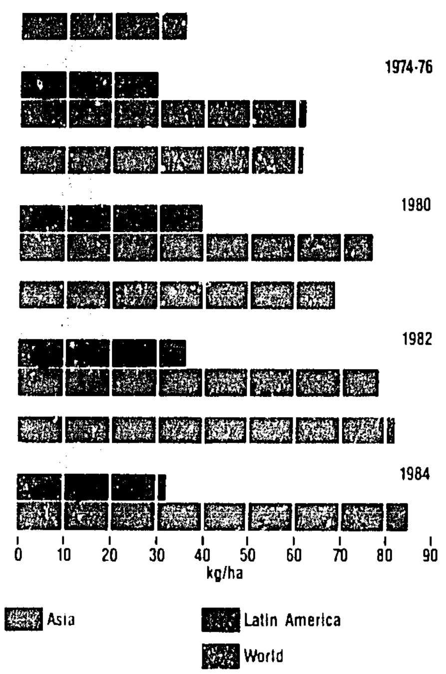


Figure 2. Fertilizer Use Per Hectare.

grain increase in the developing countries at least 50% can be attributed to increased fertilizer use.

According to FAO, only 16% of the soil resources in Africa have no serious limitation for crop production. The remaining 84% of the soils experience serious limitations for production. Furthermore, productive soils are being lost through mismanagement, erosion, encroachment of the desert, and deforestation.

Higher crop yields, multiple cropping, and an increase in productivity of marginal lands will not be possible without an increase in fertilizer use. Organic manures and plant residues are important sources of nutrients, but they cannot supply all of the nutrients needed to grow food in order to feed Africa's expanding population. Consequently, there is no substitute for chemical fertilizers in order to meet the expanding requirements for plant nutrition. Moreover, modern crop varieties cannot achieve their genetic potential yields unless good soil fertility is maintained. This can be achieved economically and on a large scale through increased use of chemical fertilizer.

The level of and growth in fertilizer use in Africa are extremely low with use levels fluctuating widely from year to year. In 1986 only 3.7 million mt of fertilizers (NPK) was used in all of Africa, hence, less than 3% of the fertilizer used worldwide. Even more alarming is the fact that fertilizer use during the past decade increased by less than 5%/year—from a base of only 2.38 million mt in 1976. In many cases fertilizer use has stagnated. Sub-Saharan Africa's fertilizer consumption rate is 6.4 kg nutrients/ha; much of this is used on export crops rather than crops that feed the people. This consumption rate is the lowest in the developing world. Africa as a whole consumes only 18.5 kg fertilizer/ha (Figure 2).

As in most regions of the world, nitrogen is the nutrient applied in the greatest quantity in Africa. In 1986 nitrogen use totaled 2 million mt (Figure 3). As for intensity of nitrogen use, during 1984 Africa as a whole used only 10 kg nitrogen/ha as compared with an average of 37 kg/ha for all developing countries. Even though nitrogen production in Africa grew at 10.9%/year during the past decade, the overall production base was low and, therefore, its respective share of world nitrogen production climbed only slightly and reached a total of 1.7 million mt in 1986 (Figure 3). The African share of the world nitrogen market was only 2.0% in 1986.

For the 10-year period ending in 1986, Africa posted an annual increase of 4.4% in phosphate use, but

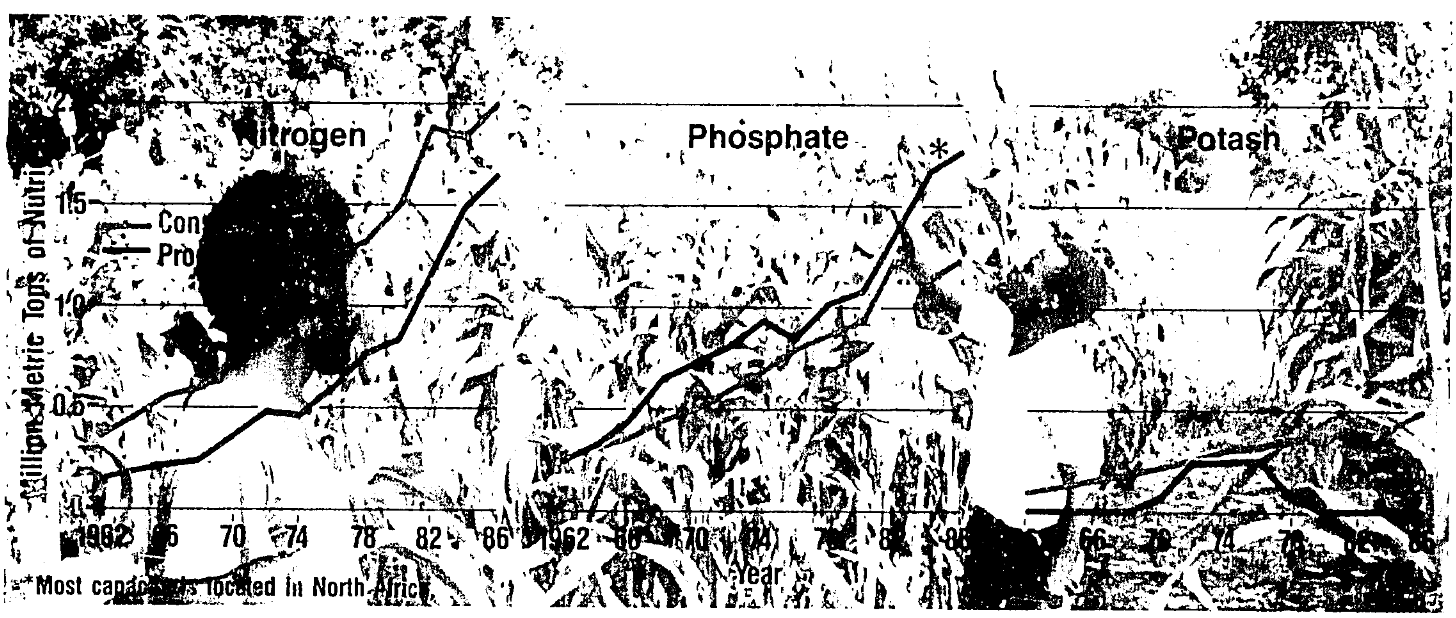


Figure 3. Fertilizer Production and Consumption Trends for Africa, 1962-86.

because of its low use base, accounted for only 4% of the world total in 1986. However, phosphate production in Africa has increased 7.7% annually during the past 10 years, as compared to the world average of 3.3%.

Africa's average annual compound growth rate in potash use was 4.2% for the decade ended in 1986, although most of the potash is produced and used in the developed countries.

Accelerating the economic use of fertilizer in Africa will require appropriate technology and major policy reforms. Those countries having the indigenous resources needed to produce fertilizers may be able to save valuable foreign exchange by manufacturing their own fertilizers. Countries with stagnant fertilizer markets are generally those that depend exclusively on imports. The high cost of imported fertilizers and the unavailability of foreign exchange are reportedly preventing the expansion of fertilizer consumption in Sub-Saharan Africa.

Improved marketing systems can be a major factor in improving the levels of fertilizer use in Africa by ensuring that the proper types of fertilizers are available at the lowest possible cost and in the quantities required by farmers at the time of planting. An often overlooked impact area is that marketing (including distribution) costs often account for a major share of the delivered cost of fertilizer. By reducing the marketing costs and, of course, the prices, increased returns are potentially available to the farmer.

Dr. Paul L.G. Vlek, Director, IFDC-Africa Division, addresses the participants in the WAFMEN Workshop, held in Togo, March 1986. Others pictured are: from left, Sandro Alderighi, FAO Representative in Togo; Komi D. Adzomada, Directeur de Cabinet, Ministère de l'Aménagement Rural; Dr. Vlek; The Honorable Minister S. Kortho, Minister of Rural Management; and Dr. A. K. Allaglo, Directeur de l'Institut National des Sols, Lomé, Togo.

The IFDC Approach to the African Puzzle

By means of research activities, technical assistance, training, and national programs, IFDC is addressing the specific problems that confront Africa. This work involved a total of 18 African countries during 1986.

Of special significance is the fact that the Center was successful in establishing an Africa Division in Togo with the assistance of the Togolese Government. Funding was pledged for core support or specific programs by the United Nations Development Programme (UNDP), International Development Research Centre (IDRC), the U.S. Agency for International Development (USAID), the World Bank, Rockefeller Foundation, and the Dutch Government. The overall goal of the Africa Division is to increase food availability by overcoming the constraints to fertilizer use and by promoting the use of indigenous resources as fertilizer raw materials. Specific objectives are to fill the training needs of the fertilizer sector, conduct and promote research, and provide technical assistance for sector development.

Research Activities

During 1986 IFDC conducted research activities in Africa that focused on nitrogen, phosphate, sulfur, and the economics of fertilizer use. The Africa research network now involves national scientists from 14 different countries, who are working together in a cooperative effort to find ways of economically using nitrogen, phosphate, and sulfur fertilizers in general and, more specifically, ways of using indigenous raw materials from Africa in producing phosphate fertilizers. This network, known as the West African Fertilizer Management Evaluation Network (WAFMEN), is sponsored by IDRC of Canada.

Through this approach, scientists at the national institutions are able to share their experience and observations through the use of similar experimental designs, combined data analysis and interpretation, and personal interaction at annual workshops.

Nitrogen Research

Collaborating scientists within the WAFMEN program have conducted uniform trials at several locations across West Africa examining the

Locally grown vegetables are sold at a farmers' market in Togo.

efficiency of the use of point-placed urea in upland crops and comparing the use of calcium ammonium nitrate (CAN) versus that of urea in maize production. Through the use of ^{15}N-labeled fertilizers, losses of nitrogen in the Sahel (semiarid zone) were found to be high (up to 50% of applied urea-nitrogen) while losses in the subhumid zone have been much lower (10%-20%). It is believed that the severe nitrogen losses in the Sahel were due in large part to ammonia volatilization. Thus, in this region, CAN (which has a low volatilization potential) was found to be superior to urea. Conversely, in the subhumid zone where losses were not such a problem, no difference was noted between the efficiency of urea and CAN. Given the higher price of CAN, urea seems to be the better nitrogen source for the subhumid zone.

Further research on the efficiency and management of nitrogen sources was conducted by IFDC scientists stationed in Niger. This work was carried out through a collaborative arrangement with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This research work was primarily concerned with millet. The wide spacing of millet grown in Niger necessitates that the plant explore a large area if it is to receive maximum benefits from broadcast fertilizer. Previous attempts to improve nitrogen uptake by deep-point placing all the nitrogen as urea near the plant resulted in poor efficiency due to severe volatilization losses (53% loss) even though the nutrient was in the soil at a depth of 6 cm. At Sadore, Niger, in an attempt to improve spatial availability of the nitrogen without promoting volatilization, CAN was used in a point placement technique. This was compared to urea deep point placed, CAN broadcast and incorporated, and urea broadcast and incorporated. In terms of fertilizer uptake by the plant, the less volatile CAN performed better than urea (Table 1). Point-placed CAN was the superior treatment, probably because the nitrogen was located near the plant and, therefore, more easily taken up by the plant roots.

A long-term trial examining the effect of crop residue on millet grain yield has been conducted during the past 4 years at Sadore, Niger. Rather than removing the residue after harvest, as is a common practice, it was left on some of the plots. Superimposed upon this was a ± fertilizer treatment so that the trial contained four treatments (control, fertilizer only, crop residue only, and crop residue plus fertilizer). During the first year of the trial (1983), the addition of crop residue without fertilizer had only a slight effect on yield, and it was evident that fertilizer alone was accounting for most of the yield increase in the crop residue plus fertilizer treatment (for comparison, see Figure 9, page 22, *IFDC Annual Report, 1983*). By 1986 the trends had changed significantly. While the control yields had been reduced drastically, the application of either crop residue or fertilizer allowed the land to support moderate yields (Figure 4). However, a combination of both crop residue and fertilizer resulted in rather significant yield increases. It is interesting that plots having

Table 1. Recovery of ^{15}N Fertilizers by Millet at Sadore, Niger

N Source	Application Method	^{15}N Recovery: Grain	^{15}N Recovery: Stover	^{15}N Recovery: Total
		(%)	(%)	(%)
CAN	Point Incorporated	21.3	16.8	38.1
CAN	Broadcast Incorporated	10.9	10.9	21.8
Urea	Point Incorporated	5.0	6.5	11.5
Urea	Broadcast Incorporated	8.9	6.8	15.7

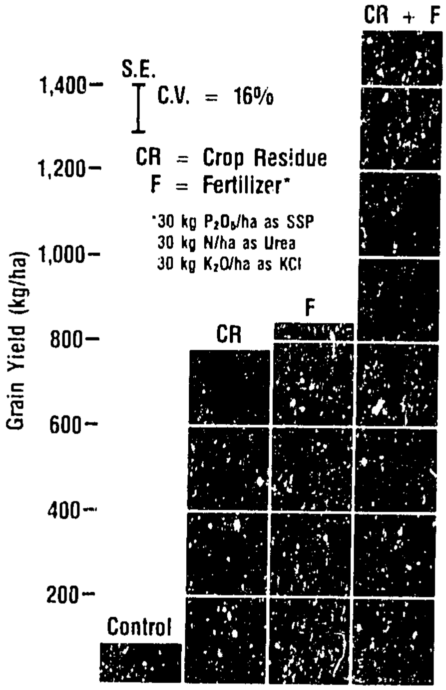


Figure 4. Effect of Fertilizer and Crop Residue Application on Millet Grain Yield (Sadore 1986).

received only crop residue and no fertilizer can continue to produce at high levels after 4 years of production while yields of control plots have declined to almost nothing. It is important to note the strong synergistic fertilizer and crop residue effect that has developed over the life of the trial. Crop residue management and fertilizer will play an important role in long-term sustained crop production in West Africa.

Phosphate Research

The objectives of the African phosphorus research program are to evaluate the potential of indigenous phosphate deposits for direct application or for production of phosphate fertilizers from these deposits at minimal cost and to develop management practices that permit the farmer to achieve maximum efficiency using these materials.

Throughout much of West Africa IFDC staff and collaborators have compared the finely ground phosphate rock from these deposits in on-station and on-farm trials against commercially available sources such as triple superphosphate (TSP) and SSP and against partially acidulated phosphate rock (PAPR), which had been prepared at IFDC Headquarters. (Partial acidulation is a process where only a percentage of the sulfuric acid required for complete preparation of SSP from phosphate rock is used, thereby reducing production costs. The resultant PAPR has a lower percentage of water-soluble and citrate-soluble phosphorus but a higher percentage of total phosphorus than SSP.)

In Niger a field trial that was initiated in 1982 was continued during 1986. Phosphorus was applied annually as Parc-W phosphate rock, Parc-W PAPR (25% and 50% acidulation), SSP with no nitrogen, SSP, and TSP or as a single dose in 1982 and 1985. In 1985 the plots were split—one-half of the plot continuing to receive phosphorus application and the other receiving no further phosphorus addition in order to study millet responses to residual soil phosphorus levels. All plots continued to receive nitrogen and potassium fertilizers. In the plots continuing to receive phosphorus, PAPR (50%) performed as well as TSP, indicating that phosphate sources made from Niger rock deposits can meet the phosphorus needs of millet as well as commercially available sources. The fact that SSP (which contains sulfur) performed better than TSP (which contains no sulfur) shows that a sulfur requirement (above that supplied by the soil) may exist for millet produced in this region under continuous cropping. PAPR that was 50% acidulated performed better than PAPR of only 25% acidulation; both showed significant improvement in yield over that produced by unacidulated finely ground phosphate rock.

In the residual phosphorus study, SSP continued to perform better

In a Togolese village market, ladies sell peppers and spices.

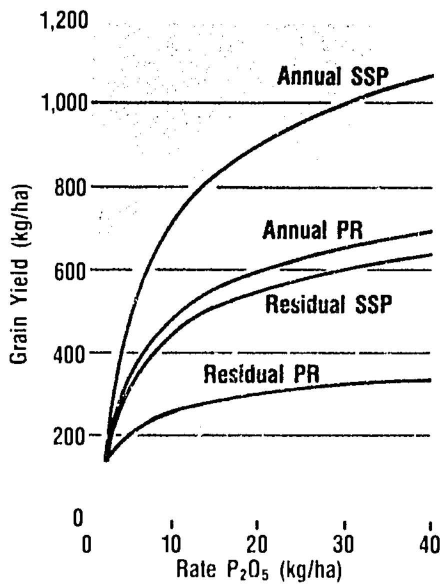


Figure 5. Effect of Annual and Residual Phosphorus Sources and Rates on Millet Grain Yield (Sadore 1986).

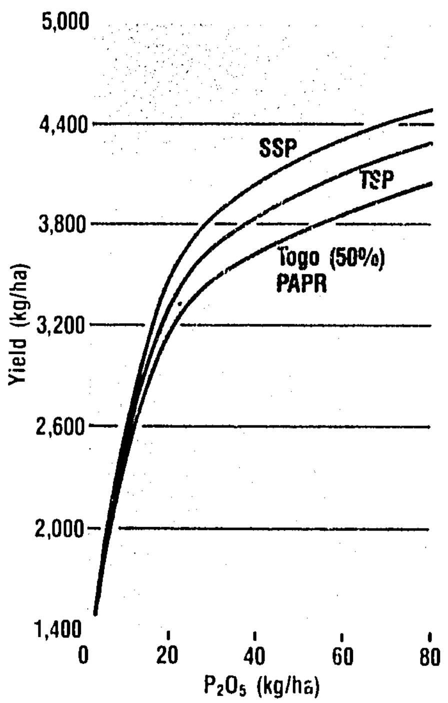


Figure 6. Annually Applied Phosphorus Source Trial (Togo 1986).

than TSP indicating a residual sulfur effect. Comparing the responses to annual phosphate application with residual phosphorus responses, it is evident that although a strong residual response was found annual applications of phosphate will be required to maintain maximum millet yields (Figure 5).

Work by WAFMEN collaborators in other regions of sub-Saharan Africa show that the phosphate rocks when directly applied generally do not perform as well as the partially acidulated materials. In some cases, this poorer performance may indicate a response to the sulfur in the PAPR materials; nevertheless, in every case, the phosphate rock improved yields over those obtained with no fertilizers. For the more reactive rocks—Togo, Tahoua (Niger), and Tilemsi (Mali), efficiencies of 70% to 98% were found when compared to SSP depending on soil type.

Partially acidulated (50%) Togo rock was tested in Togo, Nigeria, Sierra Leone, Ghana, and Liberia. In all trials where a response to phosphorus was recorded, 50% PAPR materials compared favorably with the more soluble SSP and TSP regardless of soil type (Figure 6).

Sulfur Research

The Sulfur Program participated in the West Africa Fertilizer Network in collaboration with the phosphorus and nitrogen programs. During 1986 eight experiments were carried out along a north-south rainfall gradient from dry regions of Niger through Burkina Faso to the humid zone of Togo.

The broad objectives of these trials were to:

1. Determine the requirement for sulfur in crops along an agroclimatic transect from Niger (500 mm rainfall/year) to Togo (1,500 mm rainfall/year).
2. Compare the response to and residual effects of sulfatic and elemental sulfur sources. Sulfur-containing sources tested include phosphogypsum, ammonium sulfate, urea-sulfur, SSP, and sulfur-fortified TSP.
3. Determine fertilizer-sulfur balances and compare fertilizer-sulfur leaching rates from sulfatic and elemental sulfur sources in different zones using S-35-labeled sources.
4. Examine the effect of phosphorus rates and soil phosphorus status on fertilizer-sulfur leaching.

Significant grain and/or straw dry-matter yield responses to sulfur fertilizers were observed at five of the six experiment sites in 1986, and increases in grain yields ranged from 22% to 66%. Only the Sadore, Niger, trial failed to produce any response to sulfur fertilizer. However, the millet crop at this site was severely damaged by sand storms soon after emergence, and yields were generally poor.

Sulfur fertilizer responses were observed in experiments established in 1986 in Niger (sorghum straw only), Burkina Faso (maize grain and straw) and Togo (maize grain and straw). Responses were not significant beyond the lowest rate of sulfur application (10 kg sulfur/ha in Niger and 5 kg sulfur/ha in Burkina Faso), nor were there any significant differences between sources.

Three experiments compared residual effects of sulfur fertilizer applied in 1985. Of these, millet at Sadore, Niger, gave no response. Millet at Gobery, Niger, responded in 1986, but not in 1985, and maize in Togo responded in both 1985 and 1986. Response in 1985 in Togo was not significant above the 10 kg sulfur/ha rate, and phosphogypsum was marginally superior to elemental sulfur. In 1986 significant grain yield responses were obtained with rates of up to 40 kg sulfur/ha of elemental sulfur and up to 80 kg sulfur/ha of phosphogypsum. The residual effectiveness of elemental sulfur was significantly better than that of phosphogypsum. Similarly, millet yields at Gobery, Niger, were significantly increased by rates up to 40 kg sulfur/ha, elemental sulfur again being marginally better than phosphogypsum.

Although conclusions drawn at this juncture are only preliminary, results from the sulfur trials in West Africa first indicate that sulfur deficiency is probably more severe in the subhumid than in the semiarid zones. Nevertheless, sulfur deficiencies can develop in semiarid regions within one or two seasons of more intensive cropping with sulfur-free fertilizers presumably because (1) increased yields more rapidly deplete what little available sulfur is present in the sandy, low organic matter soils of the region and (2) application of phosphate fertilizer enhances the rate of leaching of available sulfate. While the initial effectiveness of elemental sulfur and sulfate-sulfur sources are comparable, the greater residual value of elemental sulfur may be related to reduced loss by leaching. Results from the S-35 tracer studies should be informative in this regard.

Research station workers harvest microplots in a sulfur fertilizer experiment in Togo.

Economics Research

The development and use of economic analysis methodologies to evaluate fertilizer use technologies has continued in 1986. In this respect, progress was made in:

1. The development of methodology and computer application programs to access the fertilizer response information database and input economic variables and constraints to conduct economic evaluation and obtain results that can be used as guidelines for recommendations on fertilizer use.
2. The use of crop modeling to evaluate fertilizer use strategies to apply nitrogen to maize cultivation under rainfall uncertainty in selected locations of West Africa.
3. The evaluation of long-term fertilizer use strategies to apply phosphorus to selected crop rotation systems.

The results of projects involving the application of crop modeling in West Africa and a methodology to assess fertilizer response information in Mali can be used as examples of economic research conducted during 1986. To evaluate fertilizer-use strategies to apply nitrogen to maize cultivation under varying levels of rainfall uncertainty, the Crop Evaluation Through Resource and Environment Synthesis (CERES) MAIZE model was used with a weather generator program to simulate the growth of maize and its response to fertilizer in three contrasting locations in West Africa. The probability distributions of yield, obtained through the use of this model, were used in conjunction with the price of maize and fertilizer costs to obtain probability distributions of net added returns for each nitrogen rate and timing strategy. Analysis of net added returns was conducted to identify risk or efficient strategies to apply nitrogen to maize in these contrasting locations. Two management practices were compared: basal versus the best split application (one-half applied 21 days after planting and the remainder at tasseling) of urea at the rate of 69 kg/ha. The results indicate that the split application is a more risk-efficient way to apply nitrogen in the wettest and driest locations. However, in a location having medium rainfall, the basal application is a more risk-efficient way to apply nitrogen.

A methodology that accounted for the residual effects of phosphate fertilizers on crop yield and soil fertility was used to evaluate long-term (4-year) fertilizer use strategies to apply phosphate to selected crop rotation systems in Mali. Data from field experiments conducted at experimental stations and on farmers' fields in 1982-85 were used in this study. The fertilizers evaluated and compared with TSP as alternative indigenous sources of phosphorus for maize-based crop rotations were ground Tilemsi phosphate rock applied directly and also, after low-cost processing as a PAPR (30%) product. Appropriate crop response models to phosphate applied were estimated to determine the residual effects and agronomic performance of these fertilizers.

An economic analysis was conducted to evaluate the use of Tilemsi phosphate rock and PAPR (30%) as components of economically sound long-term strategies to apply phosphate to maize-cotton and groundnut-maize rotations. The objective was to identify fertilizer use strategies that maximize economic returns over a four-crop rotation period. The following strategies were evaluated in each crop rotation system: (1) application of Tilemsi phosphate rock, PAPR (30%), and TSP at the planting of each crop over the four-crop rotation; (2) basal (initial) application of 430 kg/ha of Tilemsi phosphate rock before planting of the first crop followed by no additional applications, and (3) basal (initial) application of 430 kg/ha before planting of the first crop followed by additional applications of Tilemsi phosphate rock, PAPR (30%), and TSP at the planting of each crop over the four-crop rotation.

Results of an analysis of the seven strategies indicate that Mali's resources of Tilemsi phosphate rock may be used to produce economically effective sources of phosphate for these important maize-based crop rotations and, thereby, reduce imports of fertilizers.

Cameroon workers harvest green beans.

Technical Assistance

One of the means that IFDC uses to transfer its technology is through technical assistance. The Center's staff members use a very practical, problem-solving approach in performing these technical assistance services.

During 1986 seven countries were the primary African recipients of this technical assistance. This work ranged from fertilizer sector studies to privatization strategies to supply studies.

Cameroon

At the request of the Government of the Republic of Cameroon, USAID commissioned IFDC to conduct a fertilizer sector study in that country. A study team visited Cameroon to evaluate the present system and to propose improvements.

To determine the most appropriate strategy for operating the fertilizer sector, this study covered three interlinked areas: fertilizer use, marketing, and supply. The objective of the use component of the study was to determine the most appropriate types and quantities of fertilizer needed for principal crops on the basis of agronomic and economic criteria. The marketing aspect concentrated on the amount and kind of fertilizers being consumed, physical distribution methods used, the farmer educational system, pricing methods, and fertilizer subsidy. The IFDC staff determined the cost of fertilizers delivered to farmers and identified constraints to use. The group studying fertilizer supply evaluated the economics of five alternative production schemes. These schemes include (1) domestic production of urea and diammonium phosphate (DAP) based on locally available natural gas feedstock and imported phosphoric acid, (2) world-scale urea and small DAP plants, (3) importation of finished bagged products, (4) importation of finished products in bulk with local bagging, and (5) bulk blending of compound fertilizers using imported raw materials.

The study team proposed an integrated marketing and supply system for the subsidized fertilizer sector to overcome existing fertilizer sector constraints. The system would transfer the management of the subsidized fertilizer sector gradually to separate self-supporting commercial organizations; establish a fully integrated marketing system, which would feature a network of 350-500 independent retailers; provide a strong educational program in crop production for farmers; and develop an efficient management system. During the 5-phase startup period when 326,000 tons of fertilizer would be managed, the sector system would allow savings in procurement, bagging in Cameroon, and bulk blending. It also provides for savings from a subsidy reduction and cost reductions in marketing.

The recommended strategy calls for the establishment of government-wide policies relative to (1) continued soil fertility research, (2) fertilizer subsidy reduction, (3) food crop production emphasis, (4) improved marketing system for food crops, (5) the nature of the separate self-sustaining fertilizer sector organization, (6) rural road construction priorities, and (7) the commitment of adequate foreign exchange to purchase sufficient fertilizers to meet the farmers' needs.

Ghana

The Volta Region Agricultural Development Project, acting on behalf of the Ministry of Agriculture (MOA) and with funding support from the International Development Association, engaged IFDC to study existing fertilizer and other agricultural input procurement and marketing systems and to develop proposals for privatizing the fertilizer-related processes and improving the already privatized nonfertilizer farm input system.

In Ghana fertilizer procurement and marketing are handled by MOA. The Government is considering the transfer of these activities to the private sector, which recently had been assigned similar responsibilities for nonfertilizer farm inputs.

The main objectives of the study were:

1. To identify and assess options open to the Government to achieve privatization of fertilizer procurement, marketing, and distribution.
2. To determine the optimum process for privatizing fertilizer marketing operations and to develop an implementation plan.
3. To assess the extent of government subsidy in fertilizer prices and to develop a plan for its elimination as part of the proposed privatization scheme.
4. To evaluate the performance of the privatized nonfertilizer agricultural input procurement and marketing methods and to recommend improvements.

The potential benefits of privatizing fertilizer marketing were discussed, and several options for its implementation were devised and assessed. A phased approach to privatization was suggested as the best means of effecting an orderly transition of the fertilizer procurement and marketing function from MOA to the private sector. Privatization would start at the retail level, proceed to the wholesale stage, and then reach completion with the transfer of all of MOA's provisioning, importing, and distribution functions to private hands. An implementation plan was developed including recommendations for the rapid removal of the fertilizer subsidy. The MOA would play a key role in facilitating privatization and assume responsibility for monitoring and evaluating the performance of the private sector throughout the process. The establishment of an agricultural inputs development unit was suggested to enable MOA to perform these functions more effectively.

The operation of the privatized procurement and marketing systems for nonfertilizer farm inputs was examined. Although private-sector participation is evident, the government continues to exercise a large degree of control over the provisioning, distribution, and marketing functions through price setting and sales allocations. The process is being improved, and suggestions for further improvements were made.

Guinea

IFDC provided the World Bank with a consultant to review the agricultural input supply situation in the Republic of Guinea, West Africa.

In the past agricultural development in Guinea was based on heavy government intervention at all levels.

As is the case with neighboring countries, Guinea has soils of generally low fertility, increasing population pressure on the cultivable land, and a large import tonnage of the main dietary staple, rice.

The cash-crop situation has deteriorated over the years; in particular, export earnings have been detrimentally affected. The Government is now seeking to reestablish Guinea as a source of high-quality coffee and tropical fruits and to redress the national food supply situation through increased national production.

The private sector is now very active in the importation and distribution of goods and with guidance and selection could develop the needed integrated agricultural input marketing systems. For the present, the state-run organization that is responsible for importing and distributing agrochemicals should be made financially viable by improving management and management information systems. Private-sector wholesaler/retailers need to acquire the necessary agronomic and management skills so that eventually farmers may benefit from an effective marketing system.

Kenya

At the request of USAID, IFDC conducted a study of Kenya's fertilizer sector. The primary purposes of this study were: (1) to determine the economic returns to fertilizer use on principal crops and forecast an effective demand for fertilizers and (2) to develop a strategy for promoting a market-based efficient fertilizer marketing system in Kenya.

The study points out that an estimated 2.7 million ha are planted to crops in Kenya. It was forecast that the total cropped area will expand by only about 1%/year during the next decade. Hence, any significant production increases must result from increased yields per hectare rather than through an expansion in the area harvested.

In Kenya food crops account for 83% of the total cropped area, followed by export crops with 9% and industrial crops with 8%. Primary food crops are maize and beans. Cash crops include coffee, tea, and cotton.

An analysis of existing data showed that the fertilization of maize and wheat was not as profitable as fertilization of cash crops such as coffee. The benefit:cost ratio on maize was estimated to be about 1.74. The use of fertilizers on coffee is very profitable, yielding a benefit:cost ratio of up to 27.7. The use of fertilizer on tea is also profitable, but the benefit: cost ratio is much lower than that for coffee.

The study pointed out that the real demand for fertilizers in Kenya has never been tested because of limited and/or late arrival of supplies. Even in 1986, when long rains were approaching and some 250,000 mt of fertilizers were imported, the study team found areas with shortages of appropriate fertilizers. However, it was found that some fertilizers had not arrived or were in storage awaiting shipment to customers.

The seasonality of fertilizer use in Kenya is dictated by the rainfall pattern. During the long rains, 79% of the fertilizer is used. It was estimated that fertilizer consumption would total 225,000 mt of product during the 1985/86 season. Assuming that the current distribution system is maintained, fertilizer use will reach 323,000 mt of product (139,500 mt of nutrient) in 1995. This represents an annual growth rate of 3.7%.

An integrated fertilizer marketing system in the private sector was recommended for Kenya. A transition to firms having complete fertilizer marketing capability is expected to result in fertilizer use amounting to 405,000 mt of product or 175,000 mt of nutrients by 1995.

The study recommended that a fertilizer data collecting and analyzing unit be established within the Ministry of Agriculture. This recommendation and many others in the study are being implemented.

Nigeria

A "desk study" was prepared on the technical and economic viability of setting up a 150,000-mtpy bulk-blending plant in Nigeria. The purpose of a study of this type is to make a preliminary analysis of the economics of a given facility to determine if it is worthwhile to pursue the formal study of such a venture.

Preparation of three bulk-blended fertilizers was considered to replace five grades of compound fertilizers presently imported into Nigeria. The production scheme considered the blending of urea and diammonium phosphate, (possible local production) with imported potassium chloride.

Results indicated that the expected farm-level cost per metric ton for the bulk-blended fertilizers would probably be higher than that of imported fertilizers (before profits and taxes for either case, and without considering bagging costs for the imported fertilizers). However, the cost per unit of nutrient would be lower for the bulk-blended materials than for the imported compounds due to the higher nutrient concentration of these materials.

The study concluded that the bulk-blending operation is relatively inexpensive in this case and recommended that a more thorough analysis of fertilizer prices in Nigeria be conducted since this is the most important factor determining the economic feasibility of such an installation.

Togo

At the request of the Office Togolais des Phosphates that is planning to install a multipurpose beneficiation pilot plant, IFDC supplied technical specifications for the equipment and prepared a document to solicit equipment bids on a worldwide basis. The pilot plant is a wet-flotation type plant capable of treating many ore types. IFDC will provide training in beneficiation methods and assist in future startup of the pilot plant in Togo.

Zambia

An IFDC fertilizer production specialist assessed a fertilizer production problem in Zambia at the request of USAID. Large amounts of raw materials to be used in the production of compound granular fertilizer were exposed to flooding in a bulk storage warehouse.

Inspection at the plant site revealed no damage from flooding in the bagged storage warehouse. The bulk storage warehouse, however, received severe flooding that resulted in the caking of about 3,000 mt of raw material, mostly granular diammonium phosphate. The fertilizer specialist performed a physical inventory and assessment of all the raw materials and recommended a method for crushing and reclaiming the caked material to be used as feed to the granulation plant. When the material is reclaimed, the loss due to flooding should be very small. Several technical suggestions for improving the recordkeeping and operation of the granulation unit were also made.

National Program—Mali

National programs can be thought of as "Partnerships in the Transfer of Technology." By cultivating friendships with our counterparts in developing countries, we establish an avenue through which can pass the various ideas (products and practices) that are conceived jointly so that they can be planted and reach fruition in farmers' fields of the developing countries for which they are intended.

As a result of favorable rainfall amounts and distribution, many parts of Mali reaped bountiful harvests of grain during 1986. During this time of temporary surpluses, Mali is diversifying its agriculture to include fruits and vegetables.

Because of the transitional nature of today's developing-country agriculture, many of these countries are facing a changing set of challenges. Mali, one of our national program partners, is itself confronting different challenges. Like many other countries of the tropics and subtropics, Mali must deal with the realities of an uncertain climate. However, the cards were stacked in their favor during 1985 as Malians experienced favorable rainfall amounts and distribution, and many parts of the country reaped bountiful harvests. During this time of temporary surpluses in Mali, the national program component has the opportunity to better define soil-water-fertilizer interactions and particularly as they apply to proper tillage techniques as a means of efficiently harvesting the limited amounts of rainfall. Like other developing countries, Mali is now trying new approaches to food production such as diversification to include such crops as mangoes, green beans, tomatoes, carrots, and soybeans.

During this period of transition, the IFDC phosphate project in Mali has assisted that country in its search for ways to use its indigenous resources in producing fertilizers. This work can now be used as a model for similar projects in other African countries.

Efficient Use of Phosphate Fertilizers

In developing countries such as Mali, having limited income and foreign exchange earnings, emphasis must be given to the potential development of indigenous fertilizers produced from

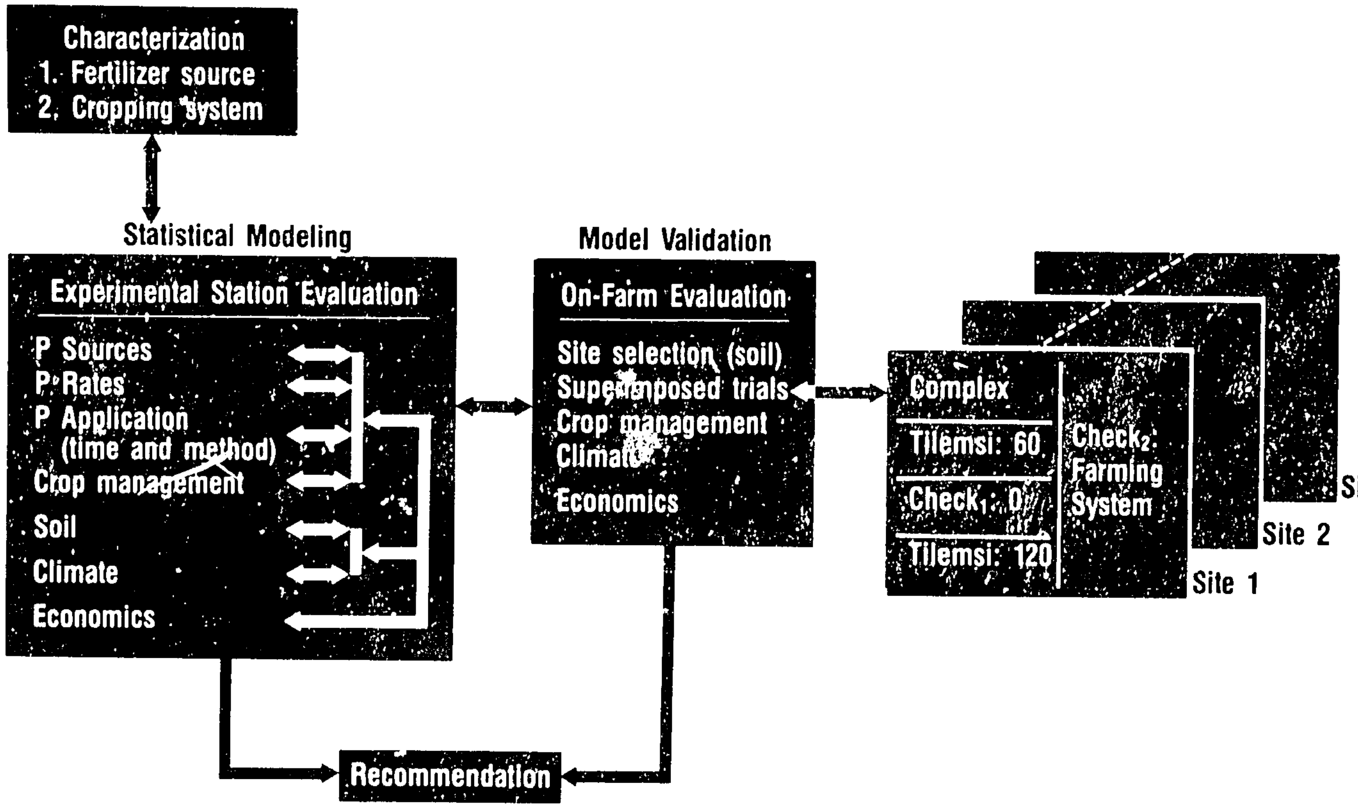


Figure 7. Integrated Research Station and Farm-Level Fertilizer Evaluation Plan.

local raw material reserves in order to decrease foreign exchange outflow and yet increase food and industrial crop production. Maximizing the efficient use of Tilemsi phosphate rock by the Malian farmers through agronomic and economic evaluation of indigenous phosphate-based fertilizer sources and their management in different agroclimatic regions of the country is the main objective of the Mali phosphate project.

A sedimentary deposit of about 20 million tons of phosphate rock containing about 27% P_2O_5 is located in the Tilemsi Valley. Grinding facilities with a potential of 50,000 tons per year are available nearby. Due to the lack of an integrated marketing system, however, actual production has been very low and variable over the years.

With project support from IDRC and funds allocated to the Compagnie Malienne Pour le Developpement des Textiles (CMDT) by the World Bank, IFDC in cooperation with the Institut d'Economie Rurale has made an indepth study of the value of Tilemsi rock-based phosphate fertilizers. The IDRC project, which was started in 1981 and will end in 1987, is based on research station fieldwork. The CMDT work, which was started in 1983 and will also end in 1987, is based on farmers' field trials. The overall methodology developed in conducting these projects can be used as a model for developing national programs in other countries of the sub-Saharan region. The integrated research station and farm-level fertilizer evaluation plan is illustrated in Figure 7.

After characterization of both the various fertilizer sources to be tested and the cropping patterns on which experimentation was to be conducted, experiment station evaluation was completed at 10 selected research station sites, representing the major soils, climatic patterns, and representative cropping sequences in Mali. This experimentation was designed to provide a statistical response model for phosphate application in Mali. Experiments were continued at five research stations in 1986.

The experiments were designed to provide information on crop response to basal or annual phosphate applications alone and a combination of basal and annual applications. Placement methods were also evaluated. All plots received equal amounts of nitrogen, potassium, and sulfur, isolating the effect of phosphorus.

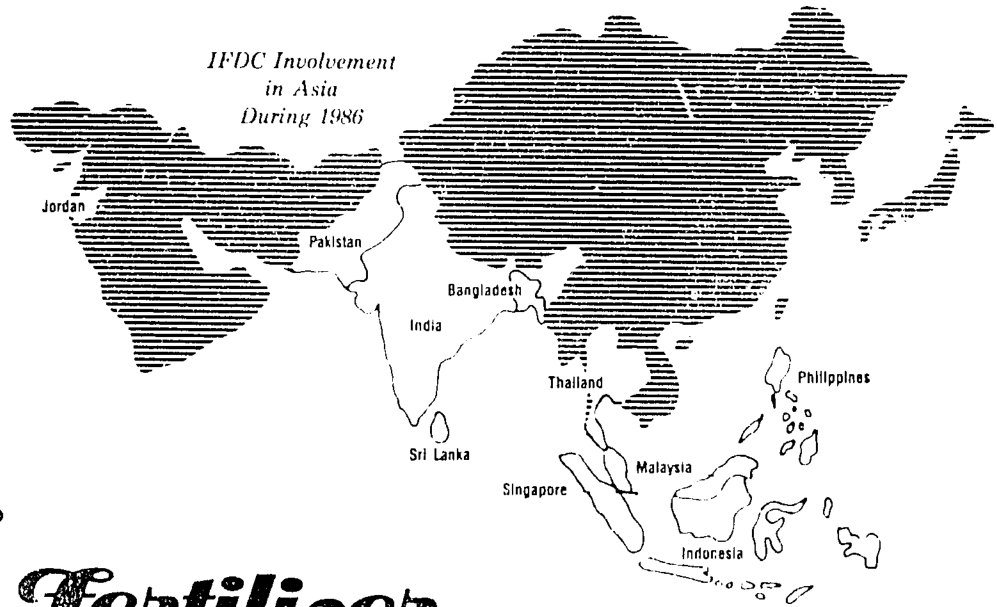
In order to validate experimental results under farmers' conditions, very simple unreplicated experiments on 96 farms comparing the present

N-P-K-S and boron formula (14-22-12-6S-1B) at rates of 150 and 100 kg/ha on cotton and maize, respectively, with Tilemsi phosphate rock at two rates (60 and 120 kg P_2O_5/ha), and a phosphate check were superimposed in farmers' fields. In addition, with Tilemsi phosphate rock as the basis for fertilization, 40 additional trials were set up to assess and quantify the need for supplementary fertilization. These trials were dispersed farmer-managed experiments. By carefully monitoring the rainfall and the farmer's crop management practices and injecting these factors into the response model, IFDC was able to make available to extension services and the Institut d'Economie Rurale a powerful tool for developing fertilizer recommendations.

This approach involves both research and the extension service and enables extension agents to quantify for the farmers the impact, in terms of yield and economic return, of given fertilizer and crop management practices.

Results

Results from IFDC trials show Tilemsi phosphate rock to be an effective alternative to imported phosphate fertilizers, both agronomically and economically, provided adequate fertilizer management in terms of time and method of application and proper cropping practices, such as optimum planting date, are adopted. An integrated marketing approach involving production, distribution, and research and extension components is needed to develop the use of Tilemsi rock.



The Asian Situation: Food and Fertilizer

Agriculture in a State of Flux

Already the home for 60% (an estimated 2.9 billion in 1986) of the world's population, Asia now is faced with the task of finding ways to accommodate an additional 700 million people estimated to be added to the region by the year 2000, bringing its population to 3.6 billion.

The land resources available to accommodate Asia's expanding population are very limited. In fact, the region contains only 25% of the world's arable land, most of which is already under cultivation. Therefore, most of the additional quantities of food and fiber required to meet the demands of the region's population must come from increased productivity of land already under cultivation.

Farmer employs typical Indian farm-level transport.

By applying a variety of appropriate products and practices, including high-yielding varieties, fertilizer, herbicides, insecticides, and irrigation, a number of countries in Asia have already achieved or soon will achieve self-sufficiency in the basic commodities of wheat and rice. India achieved self-sufficiency in wheat production in 1977 and has since shifted considerable hectarage in the Punjab to the production of rice. As a result, India is now self-sufficient in rice also. Equally impressive increases in rice production have been achieved by Bangladesh, China, Indonesia, and the Philippines. All are at or near self-sufficiency in that commodity. Both Indonesia and the Philippines have also set their sights on becoming self-sufficient in maize, and the Philippines has developed a clear strategy for exporting substantial quantities of that commodity to Taiwan, South Korea, and Japan.

Major shifts are also occurring in the production of industrial crops as well. The world sugar market has been weak in recent years. As a result, the Philippines and Thailand, net exporters of sugar, are converting land previously used for sugar production to the growth of other crops. Rice, maize, vegetables, and fruit production are involved in this shift. Equally impressive changes are occurring in oil palm and rubber. Traditionally Malaysia has been the dominant producer of both oil palm and rubber in that region. In recent years large plantings of oil palm and rubber have occurred in Indonesia, with lesser but significant quantities in Thailand and the Philippines. As a result of these shifts in the production of food and industrial crops, the agriculture of several Asian nations is becoming increasingly diversified.

The Fertilizer Sector in Transition

Because the Asian agricultural sector is in a state of transition, the fertilizer needs of the region are also changing. The fertilizer sector faces the challenge of providing a new mix of products to fill these needs.

The impact of these changes depends on the crops in question. For example, industrial crops such as oil palm and rubber as well as fruits and vegetables require a larger proportion of their nutrients as phosphate, potassium, and possibly magnesium and sulfur compared to rice or wheat where nitrogen and some phosphates are the basic needs. As new modern varieties are introduced, fertilizer needs change. The hybrid maize varieties require much larger quantities of nitrogen than traditional maize varieties, and both require much larger quantities of potash than most other crops. Many farmers prefer to apply these nutrients as a compound fertilizer where all nutrients are included. The challenge is to accurately identify the shifts in fertilizer requirements now occurring in the market, to target the areas of new demand, and, most importantly, to develop fertilizer programs and marketing systems designed to meet these changing needs in a cost-effective manner.

Asia has successfully employed an appropriate package of inputs to achieve self-sufficiency in food production in several areas, and, in the process, fertilizer consumption has increased dramatically over the past decade from 16.3 million mt of plant nutrients in 1976 to over 38.7 million mt in 1986. This represents an annual growth rate of 9.0%, more than twice the world average of 3.4%. Asia now accounts for 24% of the world's fertilizer production and 30% of its consumption. This compares to only 15% and 18% of world production and consumption, respectively, a decade earlier.

As for individual nutrients, Asia is not only the largest but also the fastest growing nitrogen market in the world. Starting from a base of 10.7 million mt of nitrogen in 1976, consumption in Asia grew at an average annual rate of 9.8%, twice the world average of 4.9%, and reached 27.7 million mt in 1985 before declining to 27.1 million mt of nitrogen in 1986 (Figure 8).

When we consider the intensity of world nitrogen use, we find that during 1984 Asia was second in intensity of use with 56.4 kg nitrogen/ha. On the production side, the events of the past decade have propelled the Asian region into the position of world leader in nitrogen production. Starting from a base of 9.5 million mt of nitrogen and 21% of the world market in 1976, nitrogen production has increased steadily over the decade at an annual compound growth rate of 9.9%. As a result, total nitrogen production for the region reached 24.3 million mt of nitrogen and represented 33% of the world's production in 1986 (Figure 8).

Asia and the U.S.S.R. have replaced Western Europe and North America

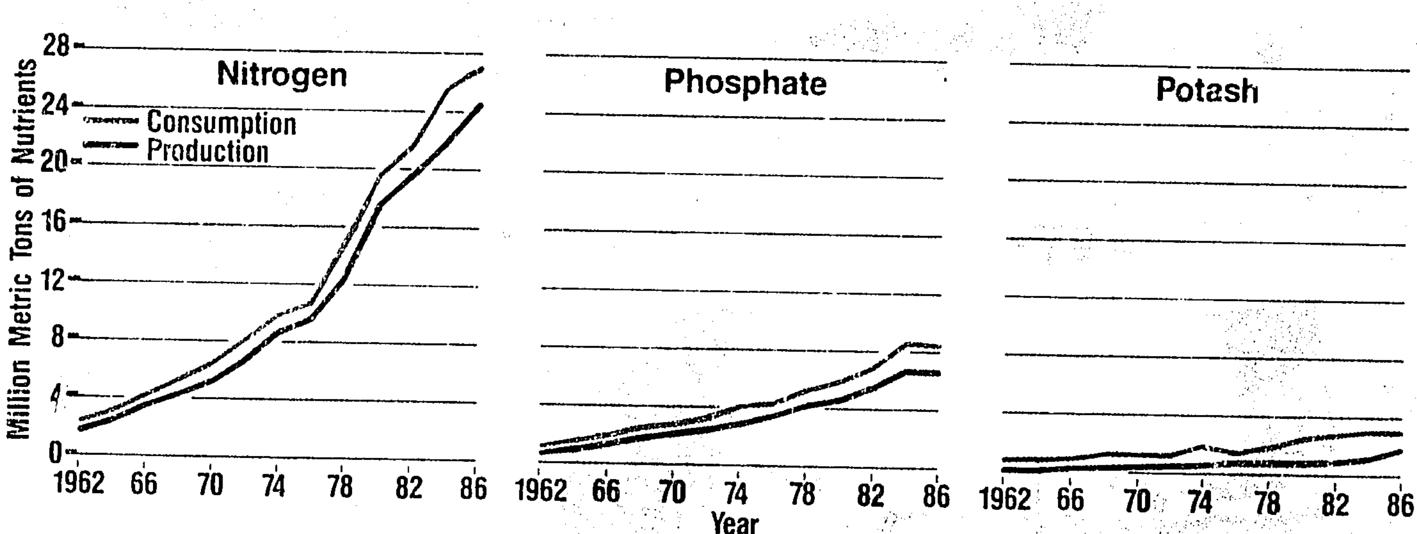


Figure 8. Fertilizer Production and Consumption Trends for Asia, 1962-86.

as the leading consumers of phosphate fertilizer. In fact, Asia accounted for 26% of the phosphate fertilizer consumed worldwide in 1986. On the production side of the scale, Asia's annual growth in phosphate production was 7.1% during the past 10 years, more than double the world average of 3.3%. In fact, Asia produced 19% of the world's phosphate in 1986.

Even though most of the potash is produced and consumed by the developed countries, Asia recorded a substantial annual compound growth rate of 7.2% in the use of that nutrient during the past decade.

As remarkable as these achievements have been, Asia still faces major problems in the fertilizer sector to which solutions must be found if this key input is to continue to play a major role in sustained agricultural productivity. Five problem areas exist in the fertilizer sector of Asia. One area that needs attention is insufficient use per hectare. In fact, Asian farmers generally use fertilizer at rates below the world average. For example, the average world use in 1986 was 85 kg/ha; for Bangladesh the rate was 61 kg/ha and for India 39 kg/ha. Other problem areas include shortages in domestic production, high production and marketing costs, low agronomic efficiency of fertilizers, and high costs of fertilizer subsidies.

The IFDC Key to the Asian Challenge

In assisting Asian countries in addressing the issues that they are confronting in their agricultural sectors, IFDC has focused its attention on research activities, technical assistance for a number of countries, and national programs in Bangladesh and Indonesia. The Center has provided innovative assistance to several Asian nations in various activities, such as restructuring their fertilizer sectors, privatizing their fertilizer industries, and enhancing the production capacity of their fertilizer plants.

Research Activities

The Center's 1986 research activities in Asia concentrated on nitrogen, involving studies on that nutrient applied to rice, sorghum, maize, groundnuts, and millet in the Indian semiarid tropics and lowland rice and mungbeans in the Philippines. This research would not have been possible without the cooperation of our collaborators at ICRISAT and the Indian Farmers' Fertiliser Cooperative, Ltd. (IFFCO) in India, the Agency for Agricultural Research and Development in Indonesia, and the International Rice Research Institute (IRRI) in the Philippines.

Nitrogen Research

Urea Supergranules Evaluated in India

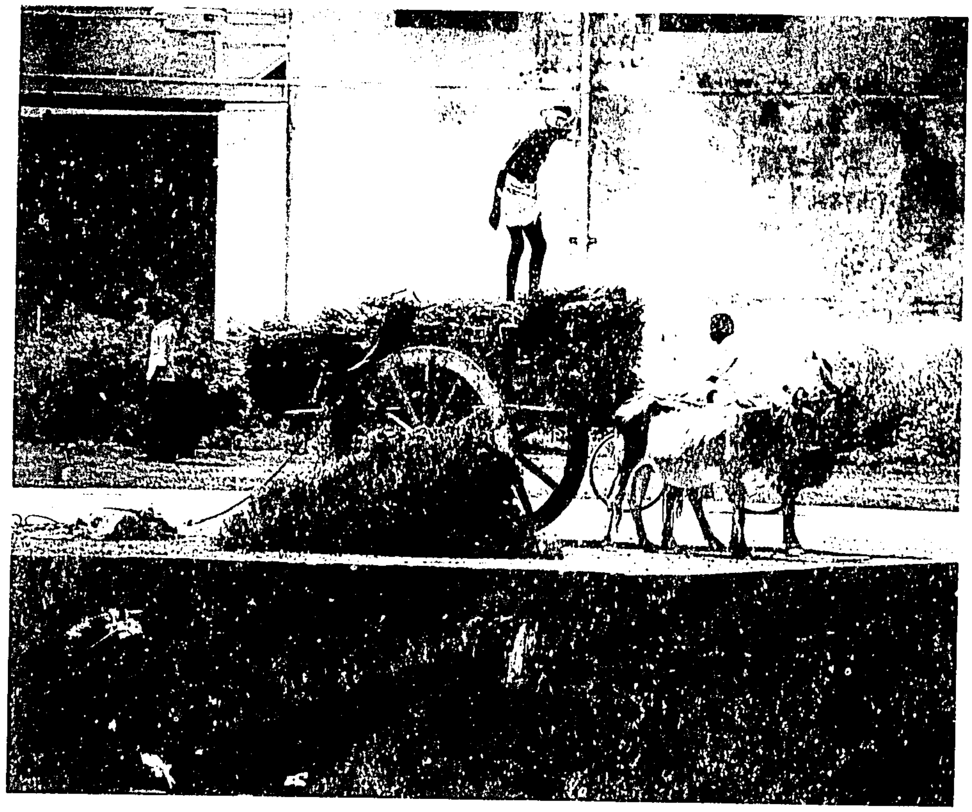
IFDC, in cooperation with IFFCO and various universities, continued to investigate the merits of deep placement of urea supergranules (USG), which has been demonstrated under a wide range of soil conditions to sharply improve nitrogen use efficiency on paddy rice. A major constraint to acceptance of this technology by farmers is its high labor requirement. The concept for hand deep placement of USG at the time of line transplanting was described in the 1985 annual report. The USG dispenser with transplanting guide was modified for field trials, which were continued during 1986 in India to determine the labor savings resulting from the combined operation compared with hand deep placement of USG a few days after line transplanting. Data were gathered on three research farms in India during the Kharif (wet) season. These 1986 results indicated a potential for a significant reduction of labor, possibly as much as one-third, depending on the situation. Rice yields for 1985 and 1986 were on par with those for researcher's technology of USG deep placement a few days after line transplanting.

A "how-to-use" booklet, describing the fabrication and use of the USG dispenser with transplanting guide, was prepared for field use primarily by extension workers. In addition to saving labor, using the USG dispenser with transplanting guide avoids damage to seedlings. It is especially attractive to economically disadvantaged

Field and research workers establish ^{15}N research in a shallow Vertisol in Hyderabad, India.

small farmers who can only afford small quantities of nitrogen fertilizer.

Obviously hand deep placement requires a special form of urea. Strategies to supply USG to the small farmer are also being investigated. In Asia most urea is produced as prills, which can be converted to USG by several methods. A promising supply strategy involves feeding prills to a pressing machine to form USG by mechanical means. The technology is simple and can be performed by dealers for a fee. The product may be 10% more expensive than prilled urea, but yield results in many soils indicate that this would be cost effective. IFDC evaluated one commercial machine rated at 250 kg USG/h and found some deficiencies, which must be overcome prior to testing on a wider scale (see also "National Programs—Indonesia"). Plans have been made to improve the machine and to look at alternative designs during 1987. Coupled with small-scale supply and improved use technique, the concept is ready for actual testing in farmers' fields.



Indian workers load wood destined for market.

Nitrogen Efficiency Studied in the Indian Semiarid Tropics

During the past 6 years, IFDC, in collaboration with ICRISAT and with the financial support of UNDP, launched a major research effort to identify the problems related to nitrogen fertilizer efficiency in the Indian semiarid tropics. The program involved research on transformations and fate of fertilizer nitrogen in soil; identification of soil and climatic factors affecting the efficiency of fertilizer use by rainfed crops; development and screening of nitrogen sources and application methodologies; influence of fallowing, cropping intensity, and intercrops on fertilizer needs and use efficiency; and water-nitrogen interactions.

From an agronomic standpoint, the most outstanding feature of the semiarid tropics is the great variability in rainfall patterns across the years and seasons. The 1982, 1983, 1984, and 1985 seasonal rainfall of 516, 913, 485, and 322 mm, respectively, provided contrasting environments for sorghum growth, yield responses, and fertilizer use efficiency studies. The research was centered on both deep and shallow Alfisols and Vertisols—the dominant soils of the region.

Nitrogen Use Efficiency—Research on nitrogen use efficiency indicates that, regardless of the quantity of seasonal rainfall, split-band application (fertilizer applied in two equal splits at planting and 3-4 weeks later in bands 5 cm deep and 5 cm away from seed rows and covered with soil) resulted in rather high (≅55%) use efficiency of fertilizer nitrogen by sorghum on the deep Vertisols and Alfisols. Losses of fertilizer nitrogen, suspected to be mainly via ammonia volatilization or denitrification from Vertisols and via leaching from Alfisols, were relatively low—$<10\%$. In high-rainfall years, nitrogen losses tended to be high (25%-30%), and consequently nitrogen recovery by plants tended to be reduced (≅45%), especially if urea was placed on the surface or incorporated to a depth of about 10 cm rather than placed in bands.

In contrast to deep soils, nitrogen losses on shallow soils, even when the split-band method of application was used and in low-rainfall years, were comparatively high (≅30%), and the use by the crop was low. The percentage of fertilizer nitrogen lost increased to more than 50% when urea or DAP was replaced by nitrate fertilizers. These results indicate that leaching and denitrification are the possible nitrogen loss mechanisms in shallow soils.

Of the 30%-40% fertilizer nitrogen remaining in the soil at harvest, only 4% was used by the subsequent crops over a period of 2 years.

Response to Fertilizer Nitrogen—Our research conclusively established that there exists a considerable potential for increasing yields of cereals like sorghum and millet by judicious use of fertilizers. Increases in yields from 1 to 4 tons/ha were achieved during several seasons through the application of 30-90 kg nitrogen/ha. Translated into agronomic efficiency, each kilogram of nitrogen produced 9-51 kg sorghum grain with a mean value of approximately 25 kg. Since the cost of fertilizer is about four times as expensive per kilogram as is the food that it is used to produce, an agronomic efficiency of 25 kg grain per kilogram of nitrogen is equivalent to a value:cost ratio of 6. An additional benefit from fertilizer application was seen in a significant increase in protein content of sorghum grain.

Similar to variations in fertilizer nitrogen recovery by the crop were the variations in response to applied nitrogen from year to year depending upon the rainfall and soil. On shallow Alfisols 30 kg nitrogen/ha increased sorghum grain yield by 500-700 kg/ha in years of drought like 1984 and 1985 (mean seasonal rainfall, 300-400 mm). No benefit from additional nitrogen application could be achieved. Strikingly, in a year of heavy rainfall (900 mm) practically no response to added fertilizer was obtained. High loss of nitrogen seemed to be the reason. In comparison, in deep Alfisols where the loss of fertilizer nitrogen was less than 10% in high-rainfall years like 1981 (≅900 mm), a further yield increase of more than 1 ton/ha was possible by the application of 60-80 kg nitrogen/ha. Irrespective of seasonal rainfall, our data suggest that application was safer on deep Alfisols than on shallow Alfisols.

On Vertisols the response of sorghum to fertilizer nitrogen application was found to be less variable across seasons. A notable exception, however, was the very low response to added nitrogen on shallow Vertisols in high-rainfall years (1983, 900 mm), which was accompanied by relatively low use of fertilizer nitrogen (≅30%).

Sources, Time, and Method of Nitrogen Application—Several experiments on evaluation of nitrogen sources showed that either urea, potassium nitrate, or compound fertilizers could be recommended for deep Vertisols or Alfisols but that nitrate-containing fertilizers were a poor choice for shallow soils. Urea and compound fertilizers were viable options. Over the years of experimentation on Vertisols and Alfisols, split application of nitrogen (one-half of the nitrogen dose applied at planting and the remaining one-half band applied 3-4 weeks later 5-7 cm away from the seed row and 5-7 cm deep and covered with soil) was superior to broadcast methods of application in the high-rainfall years and was equal to or better than broadcast in other years. Therefore, nitrogen fertilizers should be applied in split bands to dryland crops. This methodology has another merit in that it allows the farmer to make midseason adjustments: during a season with below-average rainfall, he can withhold further fertilizer application, and in a season with above-average rainfall, he can apply more nitrogen.

Results on sorghum and millet grain yield and dry-matter production of maize over a 2-year period have shown that seed row application of moderate fertilizer doses (40-60 kg nitrogen/ha) outperformed the split-band method of fertilizer application. There was no injury to germinating seed; rather a vigorous initial growth was observed when fertilizer was placed along with seed. An additional benefit is the saving in draft power because only one furrow for seed and fertilizer has to be opened rather than separate furrows for seed and fertilizer. This method is of specific merit in the post-rainy season when topdressing due to receding moisture is not feasible. It may be more advantageous to apply fertilizer in a seed row to soils whose natural fertility is very low.

A 2-year study on the efficiency of fertilizer nitrogen in millet/groundnut intercropping system showed that recovery of fertilizer nitrogen by millet was similar whether the millet was intercropped with groundnuts or grown in a pure stand. The groundnuts did not seem to absorb the fertilizer applied to the adjacent millet row.

Based upon the response to fertilizer nitrogen in double cropping of sorghum and safflower, it was evident that additional nitrogen fertilizer application was required for both the rainy-season and post-rainy-season crops. Since there was no residual effect of fertilizer nitrogen remaining in the soil, nitrogen should be applied independently to both crops. Efficiency of fertilizer nitrogen did not vary between rainy-season and post-rainy-season crops. Interestingly, the beneficial effect of fallowing in the rainy season on the post-rainy-season crop was not constant across the years. Our results showed that the favorable effect of fallowing on the following post-rainy-season crop was marked in an average-rainfall year. On the other hand, in a high-rainfall year, fallowing was not beneficial to the post-rainy-season crop. Results of water-nitrogen interaction studies suggest that fertilizer nitrogen application positively improved the use efficiency of limited water in semiarid tropical soils.

Nitrogen Efficiency Furthered on Lowland Rice in the Philippines

In collaboration with IRRI in the Philippines, IFDC has been conducting applied research on the efficiency of nitrogen fertilizers for rice production in Asia since 1978. Staff posted at IRRI continued this work during 1986.

Effectiveness of Urease Inhibitors in Lowland Rice—Even though past research has demonstrated 20% and 60% loss of nitrogen fertilizer, which has been broadcast without thorough incorporation in rice fields, some Asian rice farmers are reluctant to change from their present methods of fertilization. Urease inhibitors offer one strategy for reducing nitrogen loss and increasing rice yield without requiring a change in the farmer's method of nitrogen application. In theory, a small quantity of the chemical urease inhibitor would be added to urea at the production stage. When the urea is applied to a rice field, the inhibitor would delay urea hydrolysis, thereby preventing ammonia buildup in the floodwater and subsequent loss of ammonia to the atmosphere.

Two urease inhibitors, phenyl phosphorodiamidate (PPD) and N-(n-butyl) thiophosphoric triamide (NBPT), were examined at multiple nitrogen rates at both Pila, Laguna, and Muñoz, Nueva Ecija, Philippines.

Amendment of urea with either PPD or NBPT reduced ammonia loss at both sites. NBPT consistently matched or exceeded PPD in the ability to reduce ammonia loss at each nitrogen rate and timing for both sites. At Muñoz, NBPT reduced ammonia loss by 94%, 96%, and 98% as compared with 82%, 54%, and 25% for PPD at nitrogen rates of 35, 70, and 140 kg/ha, respectively. Each of the inhibitors was slightly less effective at the Pila site.

Amendment of urea with either PPD or NBPT increased grain yield at Muñoz but not at Pila. An alternative management practice of broadcasting urea onto drained, saturated soil at 18 days after transplanting and 5-10 days after panicle initiation offered no apparent advantage over broadcasting urea into standing floodwater with the same timing. This practice never increased plant uptake of nitrogen or grain yield.

Dr. Roland J. Buresh and an IRRI researcher, Wilma Obcemea, collect soil samples in a cooperative IFDC/IRRI upland rice experiment in Batangas, Philippines.

Effectiveness of Urea Coatings in Lowland Rice—Although sulfur-coated urea (SCU) has been shown to be an effective nitrogen source for rice, it is expensive to produce because a large amount of sulfur, sealant, and conditioner is required. One method of decreasing the quantity of coating per weight of urea is to increase the urea granule size.

Field research was conducted in the Philippines during the 1986 dry season to evaluate four experimental sulfur-coated, forestry-grade urea fertilizers. These fertilizers were specially sized and prepared to have a uniform surface. The four fertilizers were designated by their 7-day release rate in water (SCU-36, SCU-43, SCU-70, and SCU-100). In all trials basal application of conventional, granular SCU (designated SCU-21 because of its 21% 7-day release rate in water) served as a reference treatment.

The mean grain yield was significantly greater for each of the sulfur-coated materials than for regular prilled urea applied by the recommended "best split" method. Grain yield for the four experimental fertilizers tended to be comparable to that for the conventional SCU-21. In each case, coating urea with sulfur reduced the quantity of urea required to obtain a desired grain yield. SCU-43 appeared to be the most promising of the four experimental fertilizers. The coating on urea could be reduced from 20% for SCU-21 to 12.4% for SCU-43 with no change in grain yield.

The greater grain yield with the sulfur-coated urea fertilizers than with prilled urea was apparently due to a reduction in nitrogen loss and a release of available nitrogen better matched to the nitrogen uptake pattern of rice. In an auxiliary 1986 dry season experiment, use of the SCU-70 fertilizer reduced ammonia loss by 33% compared with prilled urea. These materials will continue to be tested for confirmation.

Nitrogen Management for Simulated Rainfed Lowland Rice—Whereas past research has identified poor crop use of nitrogen fertilizers and high nitrogen losses as major problems for irrigated rice, less is known about nitrogen use and losses for rainfed lowland rice. Therefore, experiments were initiated to study nitrogen transformations under rainfed conditions and to identify effective management practices for these environments.

Research focused on the interaction between nitrogen timing and water stress. Water stress was simulated in the dry season at Pila, Laguna, by withholding irrigation during either the vegetative or reproductive phase.

Even in the presence of water stress during either the vegetative phase (unflooded 15-35 days after transplanting) or reproductive phase (unflooded 41-63 days after transplanting), grain yields were significantly increased with urea applied at 80 kg of nitrogen/ha. In all cases, the yields were significantly greater for an early (one-half basal broadcast and incorporated and one-half at 37 days after transplanting) than a delayed (one-half broadcast at 11 days after transplanting and one-half at 65 days after transplanting) application of urea. Early nitrogen application apparently improved plant vigor, thus enabling the rice crop to better withstand moisture stress during the vegetative and reproductive phases.

Grain yield was lower in the water stressed than unstressed, continuously flooded treatment. This reduction in yield tended to be greater when the stress occurred during the vegetative rather than the reproductive stage of growth.

Nitrogen Loss in a Mungbean/ Lowland Rice Cropping System— Rice-growing soils in tropical Asia frequently are aerobic during the dry season but then become waterlogged through either irrigation or rainfall in the wet season. The aerobic environment could favor the buildup of soil nitrate which in turn might be lost upon waterlogging. Field research was conducted at an IRRI lowland site to measure the accumulation of soil nitrate during and following a dry season mungbean crop and to determine the magnitude of nitrate disappearance upon flooding for a dry season rice crop. In both 1985 and 1986, mungbean was planted in February and harvested in April. The land was then left fallow with no weed control for approximately 1.5 months until flooding in June for a rice crop.

Immediately prior to the June flooding, soil nitrate averaged 22 kg nitrogen/ha in the top 30 cm in 1985 and 52 kg nitrogen/ha in the top 60 cm in 1986. Additional research showed that the tillage method used prior to mungbean planting had no effect on subsequent nitrate accumulation.

After flooding of the land prior to preparation for the wet season rice, the nitrate completely disappeared. No nitrate was detectable in the soil when the rice was transplanted approximately 3 weeks after the first flooding. Additional research revealed that less than 6% of the nitrate was converted to ammonium or organic nitrogen. The remainder of the nitrate was presumably lost by denitrification following flooding.

The high nitrate accumulation and subsequent disappearance, presumably by denitrification, suggest that losses of native nitrogen may be serious problems in lowland environments with alternate aerobic and anaerobic conditions. Soil and crop management practices that conserve and use native nitrogen are needed for environments where nitrate accumulates during the dry season.

Technical Assistance

During 1986 IFDC was called upon to provide technical assistance to six Asian countries. These activities focused on solving production and marketing problems; recipients of these services included governments, fertilizer complexes, and development organizations. Like all other technical assistance, these services were provided on a reimbursable cost basis.

India

In early 1986 a team of IFDC engineers prepared a plant layout and equipment specifications for a plant owned by Pyrites, Phosphates and Chemicals, Ltd. (PPCL) to produce PAPR from Mussoorie phosphate rock in India. The Mussoorie ore is presently being mined in the state of Uttar Pradesh, India, for direct-application fertilizer. The production of PAPR from this ore would expand their market area and help reduce the drain on foreign exchange by using indigenous resources. The PAPR also provides a portion of soluble phosphate, which aids in initial crop growth, and residual phosphate, which provides for long-term availability.

The plant was designed to produce either run-of-pile or granular PAPR at a rate of 10 mtph. The design, based on results of previous bench- and pilot-scale tests performed for PPCL, will allow the plant to be built in stages, if desired. It will also allow the development of markets for both types of product. If market response is favorable, increased production of PAPR fertilizer is probable.

Indonesia

During 1986 an IFDC fertilizer distribution specialist completed a year's assignment in Indonesia, where he coordinated a study for P.T. Pupuk Sriwidjaja (P.T. PUSRI), the company that is responsible for all fertilizer marketing in Indonesia.

The study, funded by the World Bank, was undertaken to establish an overall distribution strategy for movement and handling of fertilizer from the various production units or points of import to the consumption areas throughout Indonesia. This project was initiated by the World Bank to establish an overall plan for further extension of the distribution system in Indonesia.

PUSRI has seven specially designed bulk urea carriers, each having a capacity of 7,500 tons, that move urea from production units to bagging stations in principal ports from which the bagged fertilizer is moved by rail and road to inland storage depots in the marketing areas. PUSRI owns nearly 600 rail wagons operating in Java, the principal consuming area in Indonesia.

An international team was selected to conduct the distribution study. The team members made visits to various production units, bagging stations, ports, warehouses, etc., throughout Indonesia. The study team considered the projections of fertilizer demand over the period 1985-95. To define supply areas, import requirements, and export availability, the team considered projected production and offtake patterns of the principal fertilizers. The team also considered alternative methods for future development of the system and made recommendations for extensions incorporating new and improved methods.

The team determined logical supply areas for each production unit and integration into a total system. They determined investment requirements and the financial and economic rates of return for a number of the proposed investments.

The existing system is confirmed as being generally effective. The team recommended changes in distribution practices and the establishment of an additional bagging station in Java. They recommended extensions and modifications of other bagging stations to handle bulk import of triple superphosphate and potash. The team also recommended improved bulk and bag shipping methods and suggested changes in the rail movement pattern and use of unit trains in Java, which will reduce costs considerably.

An Indonesian lady sells the fruits of her work.

Jordan

A company in Jordan requested IFDC to perform special studies of their DAP product. The project involved performing physical and chemical evaluations of their DAP. They were looking for methods of conditioning to improve storage life.

DAP samples conditioned with a Kaolin clay, a DAP sample conditioned with a high aluminum clay, and an untreated DAP were supplied by the company for evaluation.

IFDC also provided the company with some equipment to perform physical tests onsite.

Malaysia

The Malaysian NPK granulation plant, FPM Sdn. Bhd. (FPM), which began commercial operation in 1983, continued to operate smoothly. Most of the granular products are used on rubber and oil palm estates with lesser amounts being used on cocoa and rice.

During 1986 IFDC continued to work closely with FPM on expanding the product line, enhancing product quality, and reducing production costs. The product line was increased to include a phosphate-free grade containing only nitrogen, potassium, and magnesium. Also, in response to the need expressed by the cocoa growers, experimental production of a urea-free NPK-magnesium grade was initiated. The combination of high-quality product, reasonable production costs, and the capability of the process to respond to changes in product types are expected to maintain FPM's position in Malaysia's fertilizer industry.

Pakistan

An IFDC fertilizer policy specialist assisted the Asian Development Bank (ADB) in the development of a US $150 million agricultural inputs loan to the Government of Pakistan. The specialist identified the key issues facing the fertilizer sector. These included removal of the fertilizer subsidy, deregulation of fertilizer prices, privatization of the fertilizer sector, and restructuring of prices of fertilizer raw materials, improvements in fertilizer quality control, and development of technologies that increase fertilizer efficiency and lead to an environmentally sensitive agriculture.

Philippines

Continued Assistance to PHILPHOS—IFDC assisted the Philippine Phosphate Fertilizer Corporation (PHILPHOS) in their effort to increase the flexibility and cost effectiveness of their new phosphate/NPK fertilizer complex located at Leyte in the central Philippines. A major portion of the PHILPHOS production is intended for the export market. However, low international prices, a shortage of locally produced sulfuric acid, and certain difficult-to-produce NPK export grades have decreased the cost effectiveness of the plant. Assistance during 1986 focused on NPK granulation methods that would optimize raw material consumptions, particularly locally produced sulfuric acid, and improve capacity utilization, while producing certain NPK grades destined for the export market.

Fertilizer Sector Study—IFDC also provided assistance to the Government of the Philippines by providing experts to a Japanese consulting firm and directly to the Government of the Philippines to assist in the completion of a fertilizer sector study and also to highlight for the new government key issues facing the fertilizer sector, which required immediate action. This work was financed through a loan by ADB and a grant from USAID. Key findings included recommendations to (1) reduce fertilizer costs through the use of high-analysis fertilizer, development of high-speed bulk-unloading facilities; (2) define Government's role in a deregulated and privatized fertilizer sector; (3) strengthen fertilizer research particularly as related to fertilizer recommendations for phosphate, potassium, and sulfur; (4) explore ways for Government to divest itself from state-owned production; and (5) establish quality control and fertilizer information systems.

Sri Lanka

An economist and chemical engineer from IFDC assisted an ADB team in appraising a fertilizer program loan for Sri Lanka. If implemented, about 200,000 tons of fertilizer would be available during 1987/88 to sustain and possibly improve food production. The team identified other activities that would strengthen the fertilizer sector—training in bulk blending, economics, marketing, and price policy. Two other studies were suggested: bulk handling/bagging in-country and use of local rock for fertilizer production.

National Programs

Because of the successes in food production being achieved by many Asian nations through the effective application of appropriate science and technology, many of these countries are now facing a new set of challenges. This is effectively illustrated by our Asian national program partners in Bangladesh and Indonesia.

For example, Indonesia, having achieved self-sufficiency in rice a few years ago, is now intensifying its efforts in agricultural diversification. The country is striving to increase its production of upland food crops, including maize, cowpeas, and cassava, as well as industrial crops such as rubber, oil palm, coffee, and tea.

Another of our national program partners, Bangladesh, is also meeting and conquering the challenges of a changing agricultural situation. Because of its accomplishments in restructuring the distribution system, including privatization at the wholesale and retail levels, Bangladesh may soon serve as a model for other countries who would also like to transfer the management of certain segments of their fertilizer sectors from the public to the private domain.

During the current era of dynamic change in the agricultural sectors of developing countries, the national program component has the opportunity of having an even greater impact by assisting these countries in diversifying their agriculture, improving their diets, and raising their incomes through effective use of fertilizer.

Bangladesh

The eighth and final year of the USAID grant-funded Fertilizer Distribution Improvement Project I (FDI-I) was 1986. IFDC's involvement has been continuous throughout the life of the project in the form of a host-country technical assistance contract between IFDC and the Bangladesh Agricultural Development Corporation (BADC), a public-sector agricultural inputs marketing organization.

This project was designed to increase agricultural production in Bangladesh by increasing fertilizer consumption through more responsive, cost-effective marketing and distribution of fertilizer in Bangladesh. Under BADC's improved management systems and with assistance from IFDC, fertilizer availability at the farm gate has improved to the point that there is simply no longer a supply problem. During the 8-year period of IFDC's involvement in the project, fertilizer demand has increased by 79%. The primary fertilized crop in Bangladesh is rice, which receives about 75% of the total fertilizer consumption. This high percentage can be attributed to (1) rice being the largest acreage crop and (2) high- yielding rice absolutely requiring fertilizer. During the past 7 years, rice production has increased from 12.7 million tons to 16.2 million tons.

Crop diversification is gaining in popularity; fertilizer use on wheat, potato, mustard, sugarcane, and winter vegetables is expanding. Over the past 10 years fertilizer consumption per hectare has almost doubled and has brought Bangladesh from one of the lowest fertilizer users in Asia to above the average for the region.

BADC management and IFDC consultants have worked together on a day-to-day basis to improve planning, marketing management, monitoring, and efficiency with successful and measurable results.

Considering the high level of success of the Fertilizer Distribution Improvement Project I, BADC, in cooperation with USAID, has developed the Fertilizer Distribution Project II (FDI-II). This followup project will continue to have IFDC participation through a new Host Country Technical Assistance Contract between BADC and IFDC. This second phase will emphasize credit, the expanding role of the private sector in fertilizer distribution and imports, and the upgrading of BADC's role in agricultural development.

Fertilizer Pricing Policy

Market research conducted by a BADC/IFDC team in late 1981 indicated that fertilizer availability in remote areas was sporadic and that the primary constraint was dealer transport costs in excess of the government-fixed farm-gate price.

As a result, BADC made a major change in fertilizer pricing policies. Fertilizer prices were deregulated, fixed (April 1982), in only a portion of the country as a test market; on evaluation of results, price deregulation was extended to the entire country in April 1983.

There was a relatively wide group of policymakers who were opposed to this action, in the belief that fertilizer prices would skyrocket and that fertilizer demand would decline. On the other hand, the BADC/IFDC market research indicated that this would not occur primarily because of adequate supplies of product and ample competition in the marketplace.

Price deregulation did not cause a significant change in consumer prices. Although there were some adjustments, in almost all cases, these changes were related to transportation costs. In areas having low transportation costs, the consumer price of fertilizer slightly declined, and in areas having high transportation costs, consumer price increased slightly. Price deregulation caused a major improvement in fertilizer availability throughout Bangladesh.

Approach to FDI-II

IFDC believes that an effective technical assistance team supported fully by qualified Headquarters' personnel has been and will continue to be the key to successful technology transfer in Bangladesh. This integrated approach allows for effective supervision and an all-important transfer of ideas that benefit BADC, USAID, and IFDC. IFDC works closely with BADC, and all significant work is performed after input and approval of BADC. Conversely, the IFDC team is included in those decisionmaking sessions that influence the technical assistance work with which they are involved.

IFDC's role in FDI-II will be to continue the work with BADC in areas of market research, market analysis, and product development. The staff will continually assess and adjust marketing practices. A monitoring and evaluation system will be enlarged and updated to allow for collection and analysis of data on procurement, handling, storage, transportation, sales, costs, farmer practices, farmer prices (both input and output), appraisal of overall market performance, and development of policies to ensure further improvement in the sector.

Indonesia

IFDC continued to advise and assist the Indonesian Fertilizer Efficiency Program through the Agency for Agricultural Research and Development (AARD)—IFDC Joint Project under partial funding from the Australian Development Assistance Bureau.

A workshop was conducted to review program results and plan future strategies. Fifty-five participants from research institutes of AARD, the Directorate General of Food Crops, various other government and private agencies of the fertilizer sector, and IFDC attended the workshop. The membership of three Working Groups—Lowland, Upland, and Socioeconomic—was reconstituted and an Estate Crops Working Group was established.

Lowland and Socioeconomic Working Groups

Research by both of these working groups is in the area of improving nitrogen use efficiency for lowland rice through deep placement of USG.

Indonesian workers take a soil sample from phosphorus experiments.

Past activities have consisted of conducting farmer surveys, field trials, and agroeconomic analyses in three pilot areas located on Java, the main fertilizer-consuming area. During 1986 those activities were initiated in three additional pilot areas on Java. Also, farmer demonstrations were started in the Ngawi pilot area where field trial results revealed consistently favorable agronomic response and estimated net returns to deep placement of USG. Additionally, investigations were initiated to determine the potential to produce USG from prilled urea at the village level.

Testing and minor modifications of an existing briquetter, developed by the Fujian Academy of Agricultural Sciences of China and designed to produce 1-g particles at a rate of 250 kg/h, were conducted in 1986. The collaborative tests by Centre for Soil Research (CSR), Metal Industries Development Centre, and IFDC revealed a number of deficiencies in the briquetter's design and fabrication. The briquetter must have refinements in fabrication (strength of materials and precision in machining components) and addition of positive metering of substrate to operate for prolonged periods of time and to produce particles of uniform size.

Upland Working Group

In the Upland component of the project, activities have continued to focus on responses of upland rice, soybean, and cowpea (an annual rotation of three crops) to phosphorus from phosphate rock, PAPR, and TSP and to lime on Ultisols and Oxisols. While some of the soils are fairly acid, their phosphorus retention capacity is relatively low. Additionally, responses of upland rice and soybean varieties to phosphorus have been evaluated. The CSR and Central Research Institute for Food Crops have conducted six types of experiments at eight locations; these experiments resulted in more than 150 crop harvests between the 1982/83 and 1985/86 crop years.

In year-round crop rotation (rice-soybean-cowpea), rice yield responses to broadcast lime applications (0-6 t/ha) were infrequent even on soils of 75% acid saturation (hydrogen + aluminum as percent of effective cation-exchange capacity). Responses of soybeans to lime were more consistent, particularly after the first year. Cowpea responses to lime were intermediate to that of rice and soybean. Average annual benefits to lime for 3 years after application were greatest at about 1 t/ha on less acid soils and at 2-3 t/ha on the more acid soils. These rates of application began to provide a net benefit during the second year on more acid soils and during the third year on less acid soils.

The effects of liming on acid saturation of soils 3 years after application are shown in Figure 9. It required 6 t/ha of lime to reduce acid saturation to 15% at Baturaja; however, only 2 t/ha was required at Nakau. Another significant observation is that lime moved downward in the soil profile at the Nakau site while little downward movement occurred at the Baturaja site.

Crop responses to phosphorus in the presence of uniform applications of other nutrients have been studied at the eight locations for periods of from 1 to 3 years. Nitrogen was side banded, phosphorus placed in the seed row, and other fertilizers and lime were broadcast and mixed with the soil. Data for three complete years are available only from Nakau and Baturaja. As examples of responses, the average annual gross benefits by crop and the average annual net economic benefits from phosphorus fertilization for the three crops are shown in Figure 10 for those two sites. Although crop responses to phosphorus varied differently among years at the two locations, average responses were similar. Average annual net benefits to phosphorus were US $183 at 20 kg phosphorus/ha and US $244 at 60 kg phosphorus/ha. The portion of gross benefits derived from soybean, rice, and cowpea was 45%, 35%-41%, and 14%-20%, respectively, over all phosphorus rates from 0 to 60

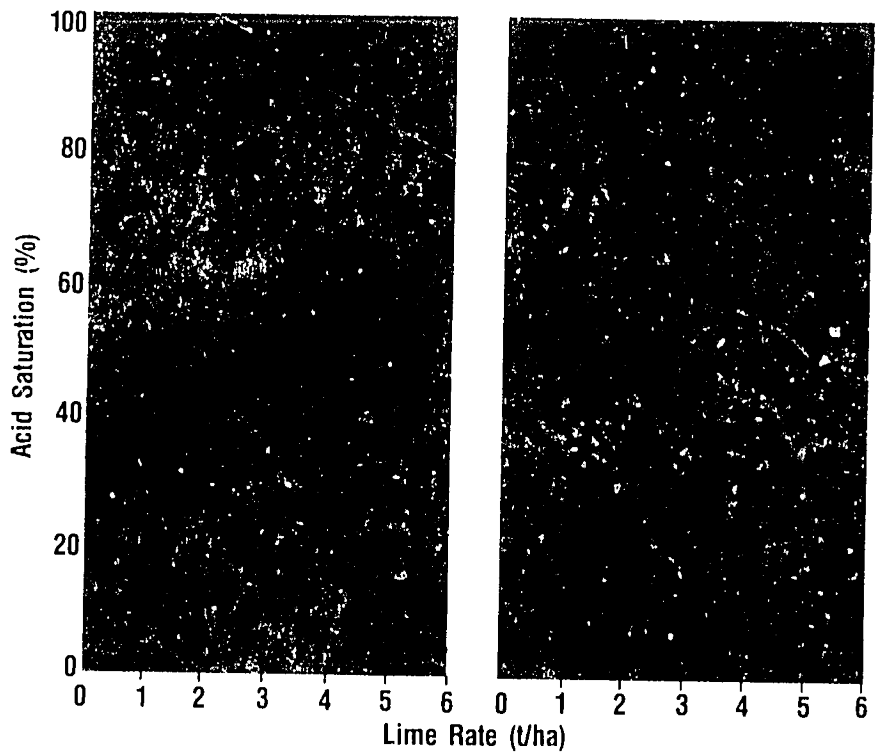


Figure 9. Effect of Lime Rates on Acid Saturation of Two Soils 3 Years After Application.

kg phosphorus per hectare. It is of great significance to farmers that significant responses to phosphorus of this magnitude may be obtained when lime is applied at only 750 kg/ha, especially on the more acid soils.

At each location a companion experiment was conducted to test crop responses to rates of water-soluble phosphorus each from TSP and PAPR (central Florida phosphate rock). Total phosphorus from PAPR was applied at a rate of 20 kg/ha while the levels of acidulation were 0%, 25%, 50%, and 75% of acid required to produce TSP. Lime was placed in the bottom of seed furrows and covered with soil; then phosphate fertilizers were placed on that soil. Nitrogen was side banded for rice only, and other fertilizers were broadcast and mixed with the soil. Lime and fertilizers were applied only prior to the rice crop during each year. Generalized crop responses are illustrated in Figure 11. On soils of 20%-30% acid saturation, the first crop (rice) after fertilization responded to increasing water-soluble phosphorus in PAPR for 1 or 2 years. In other words, responses to phosphate rock of medium reactivity were less than those to TSP. However, on soils with 50%-60% acid saturation, there were no responses to increasing levels of water-soluble phosphorus in PAPR, but yield responses to phosphate rock were similar (90%-100%) to responses to TSP from the first crop to the last crop grown during the third year. On the less acid soils, phosphate rock and TSP produced similar yield responses on legume crops during the first year and all crops during the third year. These results demonstrate a great potential for use of phosphate rock of high to medium reactivity for upland crops on a range of soils in Indonesia.

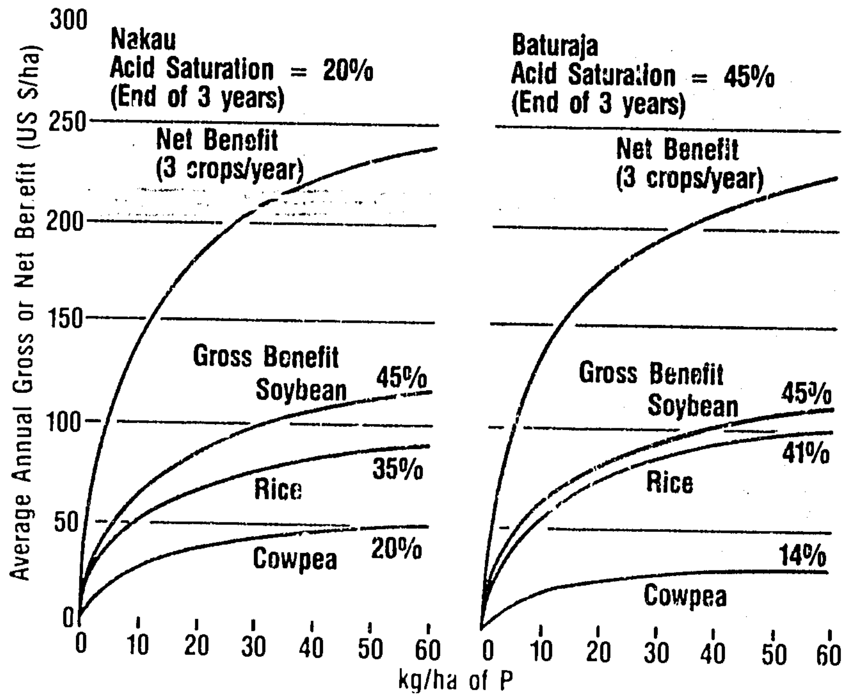


Figure 10. Average Annual Gross Benefit by Crop and Average Annual Net Benefit for Three Crops From P (TSP), 3 Years at Nakau and Baturaja.

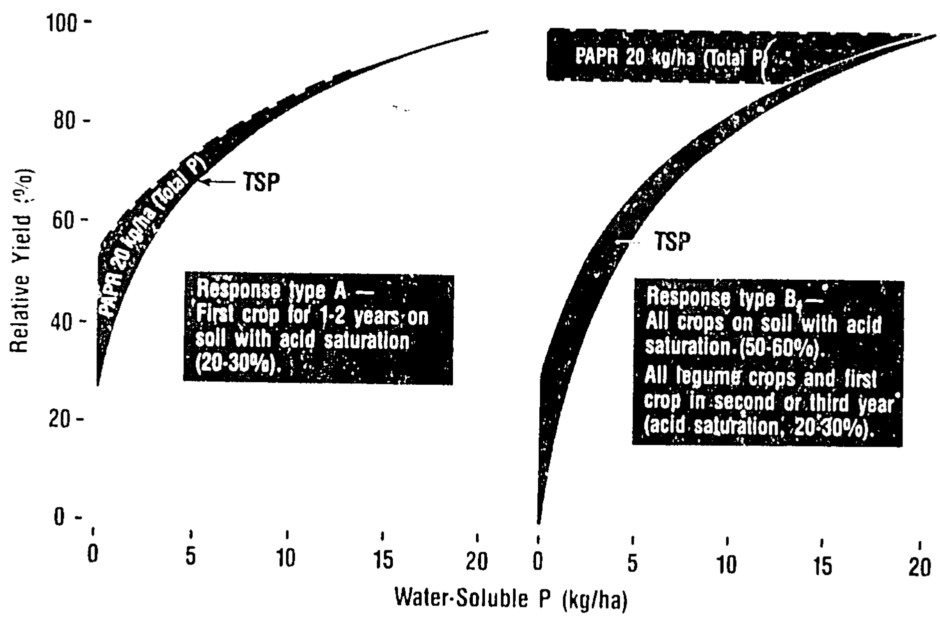


Figure 11. Two Generalized Types of Crop Responses to Water-Soluble Phosphate From TSP and PAPR (year-round crop rotation of rice-soybean-cowpea each year on soils with relatively low phosphate sorption).

IFDC Involvement in Latin America During 1986

The Latin American Situation: Food and Fertilizer

The Changing Food Situation

Among the developing countries, the most rapid increase in food production during 1960-75 occurred in Latin America where the production of primary staples grew nearly 1%/year faster than the population. In fact, in Latin America, which accounted for about 22% of the cereal production of the developing countries in 1975, the long-term annual rate of growth in cereal production was 3.5%. It is estimated that about 60% of this growth was due to the increase in area under cultivation and 40% was due to increases in production per hectare.

However, since 1980 there has been a marked decline in the region's food and nutrition situation. The downward trend of the countries' gross domestic product was accompanied by a decline in real wages and employment levels and probably by a further deterioration of income distribution. These factors have prevented the sustained development of the food and agricultural sector that was achieved in recent decades and have resulted in an unacceptable increase in the number of malnourished people and a progressive reduction in the region's food self-sufficiency. In fact, in most of the countries, per capita food production has decreased since 1980.

To reverse these trends, several countries of Latin America have implemented emergency food programs and strengthened their agricultural policies. Many Latin American countries are trying to increase their agricultural production and fertilizer consumption as part of their overall development strategy. However, the area is plagued by an economic and financial crisis caused by serious foreign debts coupled with balance of payments problems due to declining agricultural prices in an economy heavily dependent on agricultural exports.

The challenges that confront Latin America over the next few years are such that only a political solution to the foreign debt problem and an upward trend in agricultural prices can lay the foundations for development

Ing. C. A. Quiros, IFDC/CIAT Research Assistant, and a Colombian farmer evaluate a bean experiment.

and genuine investment. National food strategies must include efforts to ensure a more equitable distribution of income that will allow the affected population to purchase food or provide people with the means to produce their own food. This is of utmost importance in achieving food security for all. In order to increase production as well as incomes, high priority should be given to investing in the development and dissemination of technology to allow the small farmer to reach his full potential in the agricultural sector. This would ensure that the needs of the urban low-income groups are also met.

The Status of the Fertilizer Sector

Low prices of agricultural products in the international market, coupled with government policies of supplying cheap food to the cities, has led to a chain of direct and indirect regulations and subsidies, in which fertilizers are generally included. Therefore, the Latin American farmer, as the last link in the chain, receives a lower price for his product. Thus, his lack of interest in applying high-yielding technologies is mainly due to the impossibility of profitably investing in irrigation, machinery, fertilizers, agrochemicals, or improved seeds. This creates an impoverished agricultural sector characterized by low costs, low yields, low consumption, and consequently, lower production.

The results of the constraints to fertilizer use can be easily seen by examining the intensity of nutrient use. As for intensity of nitrogen fertilizer use, in 1984 Latin America used only 15.2 kg nitrogen/ha compared with the developing-country average of 37 kg/ha. Latin America consumed a total of 3.4 million mt of N during 1986. Looking at the region's nitrogen production, we find that Latin America, with a total of 2.9 million mt, accounted for only 4.0% of the world total in 1986; its annual growth in production of 9.0%/year over the past decade did not make up for its low overall production base (Figure 12).

Phosphate use in Latin America rose at the rate of 3.9%/year during the past decade to a total of 2.3 million mt in 1986, but its share of the world total increased from 6% established in 1976 to only 7% in 1986 (Figure 12). Per-hectare phosphate use in Latin America was 10.2 kg/ha during 1984. However, phosphate production in the region grew at an annual rate of 7.1% during the past 10 years, more than double the world average. Nevertheless, Latin America produced only 3.4% of the world's phosphate during 1986 or a total of 1.7 million mt.

Potash use in Latin America showed a substantial rate of growth, 6.0%/year, during the decade ended in 1986.

Over the next few years, Latin America will face great challenges. Receiving reasonable prices for agricultural exports will be a top priority. A sound production economy will both permit and require the application of high-yielding technologies and increased fertilizer use. The present low application of nutrients per unit of area and the technical and economic difficulty in obtaining new cropland will force producers to practice more intensive agriculture, allowing for dramatic increases in fertilizer use.

Sound development will facilitate the elimination of subsidies and will allow for reasonable import prices. Consequently, private investment will become attractive.

The challenge of the year 2000 will be the achievement, through profitable agricultural prices, of an economy of capitalization and investment, developed without protection or subsidies. The farmer will thus be able to obtain the required inputs at fair prices without the aid of subsidies. Fertilizers, which as part of high-yielding technologies have contributed toward generating an agricultural surplus, will then find a national market and profitable prices.

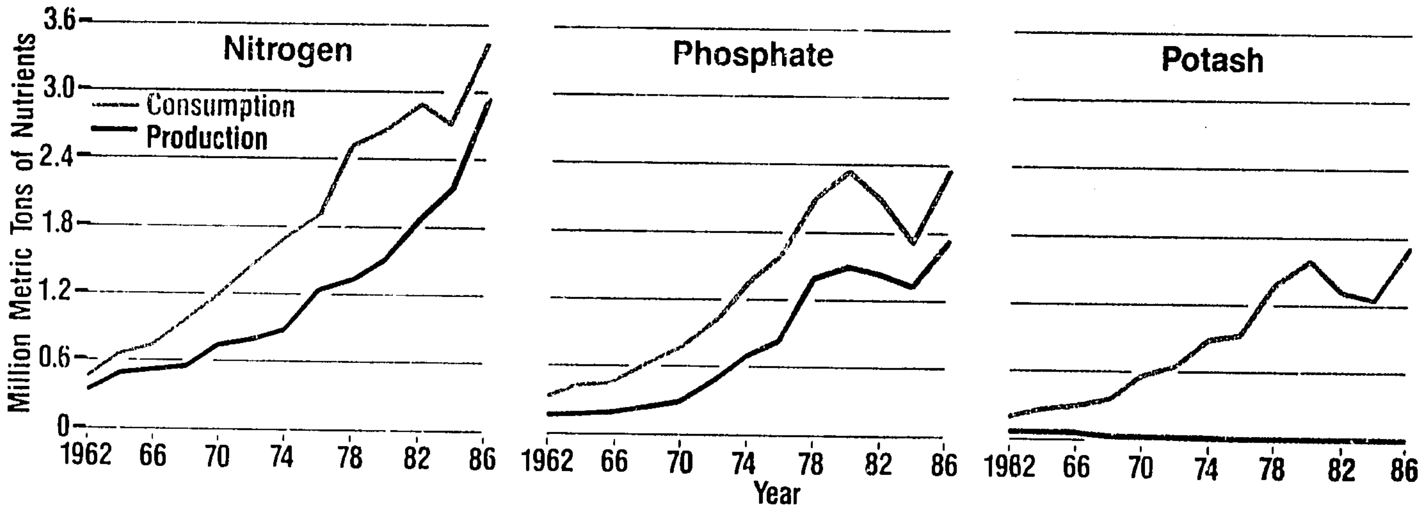


Figure 12. Fertilizer Production and Consumption Trends for Latin America, 1962-86.

The IFDC Approach to the Latin American Challenge

To assist Latin American countries in meeting the new challenges that they are facing, IFDC is primarily concentrating its efforts on phosphate and farm-level socioeconomic research and technical assistance. The purpose is to minimize foreign exchange drain through reduced imports of phosphate fertilizers and food. The phosphate project based at the International Center for Tropical Agriculture (CIAT) in Colombia is IFDC's longest running field project and seeks to find ways to use Latin America's indigenous resources to produce phosphate fertilizers.

Research Activities

During 1986 the Center's research activities in Latin America were strengthened with the establishment of a phosphate network, involving Bolivia, Colombia, Costa Rica, Ecuador, Mexico, Peru, and Venezuela. The primary focus of this network is the identification of ways to improve the agronomic efficiency of Latin American phosphate rocks in highland cropping systems. Results indicate that partial acidulation of the rock with sulfuric acid produces a less expensive fertilizer, but it is essentially equal in effectiveness agronomically to fully acidulated phosphate fertilizer. Network tests have also provided information on the most effective management practices for unacidulated phosphate rock, but PAPR continues to be superior to unacidulated phosphate rock.

Dr. L. A. Léon, IFDC Soil Scientist; Ing. C. A. Quiros, Research Assistant; and B. Garcia, ICA Soil Scientist, establish an experiment as part of the phosphate project.

Phosphate Research

The phosphate project in Colombia, funded by International Development Research Centre (IDRC) of Canada, has conducted a number of experiments in three agroclimatic zones of the Colombian Andes.

To obtain specific information related to the objectives of the project, field experiments were divided into six different types, as follows:

1. **Placement Methods**—Experiments designed to compare and measure the effect of crop production of two application methods, namely in situ placement and broadcasting, of different phosphate sources.
2. **Timing of Application**—Experiments to compare and measure the effect on crop production of fertilizer application timing, namely at planting, 15 days before planting, and 30 days before planting, of different phosphate sources.
3. **Soil Amendments**—Experiments to compare and measure the effect of soil amendments (lime and Huila phosphate rock) on crop production and their effect on the addition of different phosphate sources.
4. **Phosphate Sources**—Experiments to compare and measure crop response to different phosphate sources.
5. **Acidulation Methods**—Experiments to compare and measure crop response to different phosphate sources, specifically to compare Huila phosphate rock acidulated and granulated in the IFDC Pilot Plant using standard engineering equipment and Huila phosphate rock acidulated at CIAT Headquarters, using a simple technology, which could possibly be adopted by farmers.
6. **Mixtures**—Experiments designed to compare crop response to mixtures of phosphate sources and

nitrogen sources with acidifying products (sulfur and ammonium sulfate), with organic materials (chicken manure), and with gypsum. In these studies the effect of incubating the mixtures for 30 days was measured.

All experiments were located in farmers' fields and conducted under close supervision of IFDC staff stationed at CIAT in collaboration with the Instituto Colombiano Agropecuario (ICA) staff. None of the experiments had irrigation water and therefore depended exclusively on rainfall to obtain their water requirements. These same questions were addressed by the national scientists of the phosphate rock network using resources indigenous to each country.

Description of Experimental Areas

The three regions where experiments were established represented different agroclimatic zones typical of the Latin American mid-altitude and the highland tropics. The soils at the experimental sites range from acid to neutral; available phosphorus ranges from very low to high.

Research Results

Phosphate Use as Influenced by Product and Method of Application—Data from maize experiments indicate that maize yields obtained with TSP and point-placed Huila PAPR were higher than yields obtained when these two products were broadcast. There was no difference between TSP and PAPR though both performed better than ground Huila phosphate rock. Slightly higher yields were obtained when the phosphate rock was broadcast than when it was point placed, and maize yields were greater in the soil having lower phosphorus-fixation capacity. Findings from these experiments are consistent and confirm results obtained during previous years of this project.

The economic evaluation of these phosphate sources and placement methods indicates that greater maize yield increases, higher net returns, and higher agronomic efficiencies can be obtained with a mixture of TSP and Huila PAPR that is point placed rather than broadcast and that these two products have an overall performance much better than that of Huila phosphate rock. The estimated value:cost ratios confirm the above statements. These results indicate that if farmers are going to continue using the point-placed method to fertilize their crops in steep lands the best alternative for using local resources will be to use PAPR.

Data from bean experiments conducted to evaluate phosphate sources and time of application show that higher yield increases were obtained with TSP point placed at planting time, followed by a mixture of TSP with Huila phosphate rock having the same proportions of water- and citrate-soluble phosphate as PAPR also applied at planting time and phosphate rock applied 30 days before planting. Results of the agronomic and economic evaluation conducted using data from five experiments on beans indicate that using TSP, PAPR, or the mixture of TSP with Huila phosphate rock applied by the method most commonly used by farmers (point placement) is a profitable and sound practice.

Data from bean experiments on soil amendments indicate that the application of Huila phosphate rock as a soil amendment was more effective in soils having a relatively high phosphorus-fixation capacity and low available phosphorus. In these soils, however, higher yields were obtained when TSP was applied in addition to a previous application of 1 ton/ha of lime.

Preliminary analysis of results on the evaluation of mixtures of Huila phosphate rock with acidifying products and organic materials indicates that the best yields of beans and potatoes were obtained with mixtures containing chicken manure or TSP.

Phosphate Use as Influenced by Crop Variety—One of the most important factors limiting bean production in tropical, acid soils of Latin America is the low level of phosphorus in the soil. This is caused by extensive cropping without using fertilizers and high phosphorus fixation that limits its efficient use when it is applied. Improving phosphorus efficiency, and thus improving crop yield, requires either the development of more efficient fertilizers, the improvement of fertilizer management techniques, or the development of varieties that more effectively extract phosphorus from the soil or are able to use whatever is available more efficiently. The latter strategy can be advantageous.

Developing varieties that efficiently use phosphorus involves a formidable task of selection: this cannot be done visually. Very little is known about the nature or the processes responsible for the differences in efficiency, and nothing is yet known about the inheritance of this characteristic.

Some experiments were conducted to determine what produces efficient phosphorus use. One experiment used 26 varieties of the "Carioca" grain type. These varieties were selected because they are known to have a wide variability in adaptation to soils with low phosphorus levels. Absorption of phosphorus over time, rates of plant growth, and yield were all measured in each variety grown under both phosphorus-stressed and nonstressed fertility conditions. To determine which aspects of phosphorus uptake, plant growth, and yield component development accounted for the difference in grain yield, the varieties were classified as either efficient or inefficient based on their yields under phosphorus stress.

Total amounts of phosphorus in the plants at various stages of growth did not seem to explain the difference between efficient and inefficient varieties. The pattern of phosphorus uptake and its effect on grain yield was analyzed using path analysis, a statistical technique that makes it possible to determine which absorption periods are the most important in the development of grain yields. The results showed that during the period of 15-30 days after germination phosphorus absorption in the inefficient varieties was very important. This is a period of rapid vegetative growth. In the efficient varieties there was no such increase in the importance of phosphorus uptake during that period. This confirmed visual observations that the efficient varieties often look less vigorous during this period. Similarly, the total weight of leaves and stems and their phosphorus content at 15 days after germination showed that early vigor and phosphorus absorption had minimal influence on phosphorus efficiency.

The grain yield of beans can be divided into its three component parts: pods/plant, grains/pod, and weight/grain. Since phosphorus absorption was not closely related to phosphorus efficiency on low phosphorus soils, the yield components of efficient and inefficient varieties were studied to determine which components were most important in determining phosphorus efficiency. It was found that the efficient varieties had 6% more pods, 12% more seeds per pod, and 9% higher grain weight than the inefficient plants. It appears that the inefficient plants abort more pods and seeds under phosphorus deficiency than necessary. Thus, much of the phosphorus that is taken up by the plant is not translocated to the grain.

Even though the results of this study did not reveal absolute criteria that would make it possible to easily select efficient varieties, they point to approaches that could be employed. There was not much difference between phosphorus absorption in efficient varieties and inefficient ones. Efficient varieties actually absorb phosphorus more slowly during the first weeks. The differences between efficient and inefficient varieties are mainly related to how well they use whatever phosphorus is available. The ability of the plant to produce pods and seeds under phosphorus stress is the most important characteristic in making a plant phosphorus efficient. It is recommended that future studies concentrate on the dynamics of phosphorus inside the plant during flowering and on the morphological changes associated with it.

Rhizobium/Fertilizer Research

Inoculants carrying bacteria that allow legumes to fix nitrogen from the atmosphere are usually applied in developed countries as a moist peat mixture. This technology, however, is inappropriate for many tropical countries lacking peat sources and refrigerated storage for such agricultural inputs.

In an effort to develop an effective inoculant that will encourage symbiotic production of nitrogen, IFDC is participating in a collaborative project entitled "Maximizing Crop Production Through Biological Nitrogen Fixation." The Center is cooperating with CIAT and Boyce Thompson Institute (BTI) on this project funded by UNDP.

Studies at IFDC involve the development and appraisal of fertilizers as carriers for *Rhizobium*, with and without seeds. The project aims to improve the survivability of the inoculant in developing countries while at the same time supplying other nutrients such as phosphorus and potassium, needed by the leguminous crop. An ultimate goal is to supply a single granule containing *Rhizobium* and fertilizer.

The project is conducted in the following fashion: (1) *Rhizobium* is supplied by BTI; (2) survivability is determined by IFDC and BTI; and (3) field tests are to be conducted by CIAT. IFDC work involves preparing the *Rhizobium* culture, freeze drying, and suspending the culture in oil. The resultant suspension is then applied to fertilizer granules.

Initial results concerning the survivability of the inoculant are encouraging. The fertilizer materials that have been used are fused magnesium phosphate or phosphate rock. Granules are made using a starch binder or a rock treated with small amounts of sulfuric acid (partially acidulated phosphate rock). The *Rhizobium*-fertilizer mixture must be stored where moisture is minimized, such as in a sealed plastic bag. The mixture is tolerant to a temperature of 45°C. Figure 13 shows good survivability after 16 weeks for CIAT strain 899 (beans).

Farm-Level Socioeconomic Research

Research on farm-level patterns of fertilizer adoption was conducted in Colombia in 1986 to describe farmers' current level of technology into which new fertilizers developed by the project may be introduced and to diagnose potential acceptance by farmers of new products and practices. This research is conducted principally by social science specialists to aid project soil scientists in the evaluation of agronomic results from on-farm testing of new technology.

A study of small-scale Colombian potato farmers was conducted in collaboration with economists and an anthropologist from ICA. The study found that chemical fertilizers are applied primarily to potatoes, and rotations with other crops are used by farmers to take advantage of residual effects of potato fertilization. It was learned that 100% of the farmers use chemical fertilizers on potatoes, while 35% of the farmers surveyed have tried chemical fertilizers on maize.

Organic fertilizers also have a role in potato farming: 51% of the farmers had tried organic fertilizers on potatoes and 56% on maize. About 70% of the farmers surveyed reported using compost on crops other than potatoes.

The principal production constraints on potatoes as perceived by farmers are the availability of labor and the financial resources to pay for fertilizer. With the exception of the smallest farmers, potato cultivators were more interested in fertilizer experiments for potatoes that would allow them to increase productivity rather than in reducing costs. Labor scarcity in the system meant that farmers expressed less interest in mixtures of organic-inorganic fertilizers that might potentially reduce costs of production if these would require more labor for preparation or application of mixtures.

However, farmers in the potato-based farming system have experimented with farmyard manure supplements to chemical fertilizers to increase productivity and reported favorable results. In the farmers' eyes, the chief limitations to this fertilization strategy are the difficulties of manure supply and labor shortages. Farmers were experimenting with other approaches to intensifying land use: potato-pea intercropping has proven successful and is being disseminated from farmer to farmer in the region.

A major conclusion of the study was to recommend evaluation of experimental fertilizers and their residual effects within common rotation systems since the overall cost:benefit analysis of potato fertilization is perceived by farmers in the context of rotations. Potatoes are risky, due to price variability, but are heavily fertilized; net losses on the potato crop in any given season are seen as recoverable in terms of the benefits of residual effects for the overall food production system via rotations. A second recommendation was to expand onfarm fertilizer testing to include some of the intercropping patterns that farmers are trying, notably the potato-pea intercrop.

Field research in Colombia has also involved an analysis of the relationship between intensification of land use, through the introduction of nontraditional crops such as beans and tomatoes, which are heavily fertilized, and family structure which was found to be an important variable influencing farmer acceptance of innovations. The study found that the extended family structure provides a type of "safety-net" for young farmers, who meet basic subsistence needs from the patrimonial holding where cultivation of traditional food crops (cassava, maize, plantains) and cash crops (principally coffee) is concentrated. The extended family structure enables the younger farmers to take risks with input-intensive new crops which they cultivate on small holdings.

Field research was also conducted in Ecuador. A study was conducted in collaboration with the National Research Institute in Agriculture and Livestock (INIAP). The main crops in this system are maize, grown by 92% of farmers, potatoes (62% of farmers), climbing beans (58% of farmers), and bush beans (26% of farmers). In contrast to the potato-based system discussed earlier, only 25% of farmers use chemical fertilizers, while 83% of the farmers use organic fertilizers. Maize is the most commonly fertilized crop, with potatoes second in importance. Different sources of organic fertilizer include farmyard manure, chicken manure, and household refuse. Fourteen percent of farmers actually made compost. The low rate of adoption of chemical fertilizers in this system cannot be attributed to traditionalism: 46% of farmers had tried improved crop varieties and 46% also had used chemical pest and disease control. Few farmers, however, had received technical assistance (18.4%) or agricultural credit (14%).

The overall low rate of chemical fertilizer adoption was not evenly distributed across different farm-size groups. Farms with less than 4 ha had low adoption rates, and farms with over 50 ha used no chemical fertilizer. In contrast between 40% and 50% of farms in the size categories between 4 and 50 ha had adopted chemical fertilizers. However, it is important to note that this trend is reversed with respect to the adoption of other technologies. Very small farmers with 1 ha or less had an 80%

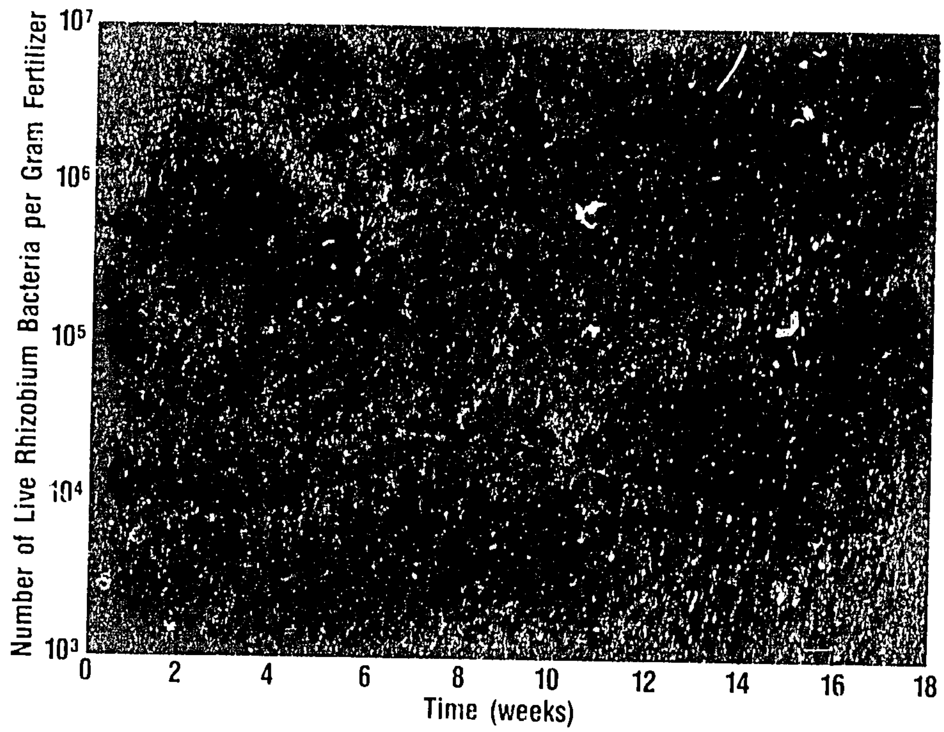


Figure 13. Survival of *Rhizobium* on Fertilizer Carriers.

adoption rate for varieties, exceeded only by the very large farms over 50 ha in size.

While these data are only in the initial stages of analysis, these preliminary figures suggest that there may be important scope for introducing cost-reducing fertilizer technology to small farms (less than 4 ha in size in this sample) where other new technologies have already been implemented.

José Rafael Castillo (left) and Adriana Sánchez of INTEVEP; Jorge Polo, IFDC Engineering Coordinator; and José Ramon Lazo de la Vega, IFDC Special Project Engineer, examine high-potash NPK fertilizer produced in the IFDC Pilot Plant.

Technical Assistance

Technical assistance in Latin America during 1986 was altogether focused on solutions to production problems. This assistance sought to achieve objectives such as improving fertilizer product quality, decreasing the potential of environmental pollution, minimizing erosion problems in fertilizer plant equipment, and increasing the production of a granulation plant.

Colombia

Abonos Colombianos, S.A. (ABOCOL) has been operating a nitrophosphate-based NPK granulation plant in Colombia for about 20 years. Changes in demand (need for high-nitrogen grades) and the need to improve product quality and decrease the potential of environmental pollution have led ABOCOL to initiate a project designed to evaluate the feasibility of a major revamp of their plant. Although the project is only in the evaluation stage, IFDC collaborated closely with ABOCOL and two U.S.-based fertilizer engineering and production organizations to determine the technical feasibility of the envisioned modifications.

Dominican Republic

A company in the Dominican Republic requested that IFDC investigate various methods to remove iron from bauxite prior to producing aluminum sulfate. Bauxite is a potential raw material for producing aluminum sulfate, which is used for water treatment. However, the iron content in bauxite must be significantly reduced relative to aluminum before it can be used to make aluminum sulfate.

The methods considered for removing the iron were: size classification, selective flocculation, roasting, magnetic separation, flotation, and selective leaching. Selective leaching of iron oxides with hydrochloric acid gave the best results. The resultant concentrate of impure bauxite was converted to aluminum sulfate solution having acceptable aluminum and sulfate contents for commercial use. A hydrochloric acid plant is under construction in the Dominican Republic to commercialize the IFDC-developed process.

Guatemala

Eleven samples of possible filler materials used in compaction of NPK fertilizers were partially characterized for Productora y Distribuidora de Fertilizantes y Agroquimicos, S.A. To minimize wear on the compaction rolls, the company wanted to reduce the quantity of silica in the fillers. The samples had been obtained from a variety of sources including both sedimentary and igneous rocks. Results of the characterization showed that five of the samples were not suitable for further consideration due to their high silica content, which would cause erosion problems in equipment.

Venezuela

Enhancing Production Capability of Granulation Plant

Instituto Venezolano Tecnologico del Petroleo (INTEVEP) is studying methods to increase production of the Petroquimica de Venezuela (PEQUIVEN) fertilizer granulation plant located at Moron, Venezuela. The design of this plant includes an atmospheric preneutralizer, a rotary-drum granulator, and hot screening of the dryer discharge material. One of the methods of increasing production being considered by INTEVEP is to feed powdered monoammonium phosphate (MAP) to the drum granulator as a replacement for part of the required recycle material, thus reducing the amount of screened product presently being returned to the granulator as recycle.

At the request of INTEVEP, IFDC provided a basic process engineering package for an installation designed to produce 30 mtph of powdered MAP. This basic engineering package contained a recommended process flowsheet, general equipment specifications, and material and heat balances necessary for the required detailed engineering.

The recommended process produces powdered MAP using a pipe-cross reactor, which discharges into a natural draft spray tower. The hot MAP crystallizes into a powder, which passes through a countercurrent, rotary cooler. The product discharged from the cooler is transferred to storage until it is reclaimed as feed to the granulation plant. It is expected that cooling will be needed to prevent caking of the product. The powdered MAP could also be sold directly or used as an ingredient for NPK or MAP granulation, or for the preparation of fluid fertilizers.

During the study phase of the project, a visit was made by an IFDC design specialist and an INTEVEP engineer to an operating installation, which uses this process for the production of 1,200 tpd of powdered MAP.

Producing NPK Fertilizer With High-Potash Content

Two Venezuelan scientists came to IFDC to study the production of high-potash NPK fertilizers. The scientists are employed by INTEVEP, S.A., the research division of Petroleos de Venezuela, S.A. (PDVSA) —the government-owned petroleum company of Venezuela.

Venezuela has resources for producing nitrogen and phosphate fertilizers, but the country must import all of its potassium requirements. At present, granular compound fertilizers containing nitrogen, phosphate, and potassium are being produced by PEQUIVEN, the fertilizer production arm of PDVSA. However, IFDC recommended in an earlier study that they produce bulk-blended fertilizers rather than homogenous granular products. Because the size distribution of the currently imported potassium compounds is not well matched with other bulk-blend ingredients, PEQUIVEN cannot use this material in producing the bulk-blend fertilizer as it would result in an uneven blend of the nutrients. For this reason, INTEVEP is looking into ways of modifying the imported potash to produce uniformly sized granules that could be used for bulk blending.

The scientists came to IFDC to determine if their existing granulation plant could be used to produce the correct granule size by granulating the potash, which would result in a more economical alternative.

The pilot-plant test runs for INTEVEP were successful. Enough information was obtained and transmitted to INTEVEP so that they can make a bulk-blend ingredient containing from 35% to 40% K_2O.

Global Training Activities

The training component continues to play a very important role in the development of technical knowledge and managerial skills of developing-country personnel in all aspects of fertilizer production, marketing, and use. More specifically, it provides a link with the developing world for the effective transfer of IFDC-developed and other technologies.

When the multiplier effect of training is considered, its impact on the development of the fertilizer sector in each respective country can be envisioned. In other words, for every participant who is actually involved in a training program, approximately 30 other people benefit from the program when the individual returns to his/her respective country and shares the information with colleagues.

These programs are conducted both at Headquarters and regionally. As for subject-matter content, the programs can be general or specialized in nature.

Typical Indian fertilizer handling is demonstrated for training participants.

Funding

The substantial financial support from UNDP to the IFDC training program component has played an increasingly important role in the success of these programs. Since 1976 IFDC training programs have provided training for more than 3,000 individuals from more than 100 countries.

Our Partners in Training: The Cosponsors

The success of our regional programs often stems from the fact that these programs are cosponsored by organizations located in the respective countries. The regionally based programs are enhanced by the contributions of the cosponsors.

Since IFDC offered its first training program in 1976, the Center has been fortunate in having some 20 organizations to serve as cosponsors for its training programs offered in various countries around the globe. Among those organizations serving as cosponsors of 1986 programs were the Fertiliser Association of India and the Assosiasi Produsen Pupuk Indonesia. In addition, CIAT hosted an IFDC marketing program during 1986.

1986 Activities

In 1986 IFDC's training-related technology transfer activities continued to be directed mainly to the areas of fertilizer production, marketing, and use efficiency research. Thirty-eight general and specialized training programs were organized and implemented. Training was afforded to 467 participants from 50 different countries.

Theo Maris (standing, center), Chief of Fertilizer Laboratories, Division of Chemistry, Florida Department of Agriculture and Consumer Services, discusses Florida's fertilizer quality control laws with training participants.

General Training Programs

During 1986 IFDC presented 11 general training programs, which included one workshop. Eight of the training programs were of global impact and were conducted at IFDC Headquarters and other locations in the United States. Three training programs were regionally focused; two were carried out in Asia and one in Latin America. The regionally oriented Workshop on African Fertilizer Sector Development was based at IFDC Headquarters and included study tours to other U.S. locations.

Of the 11 programs conducted in 1986, two dealt with fertilizer production, five with fertilizer marketing, and one with fertilizer use efficiency research. The three remaining 1986 offerings were more broadly scoped.

Some 188 individuals from 47 countries participated in the 11 general training programs conducted in 1986. Regional distribution of participants is shown in Figure 14. Asia with 50% had the highest representation followed by Africa with 31%. Nineteen African and seventeen Asian countries were represented.

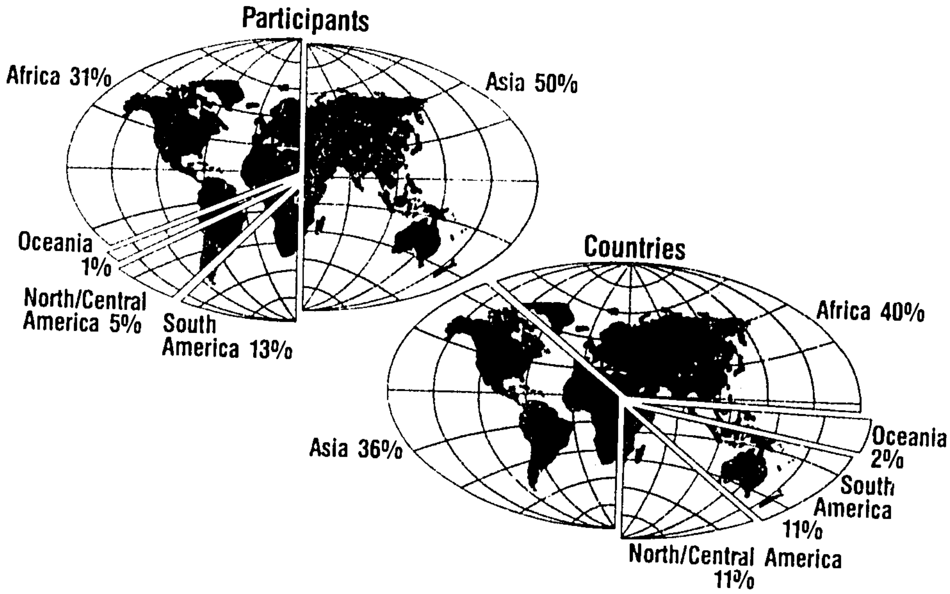


Figure 14. Regional Participation in 1986 IFDC General Training Programs.

Production

The Center's fertilizer production training programs concentrate on training plant personnel in the production of various types of fertilizer products and the maintenance and efficient operation of fertilizer plants.

During 1986 two such programs were offered. The Maintenance and Production Management Training Program was offered for the seventh consecutive year. The application of maintenance and production management theories and practices was demonstrated during field trips to commercial-scale plants in the United States. The program also featured a special workshop highlighting ammonia and urea plant operations and problems.

A new production program, Fertilizer Process Economics, was offered during 1986. The goal of this 3-week program was to provide the participants with the techniques needed to determine the economic

Indian workers load grain onto wagon.

feasibility of building new fertilizer plants and modifying or expanding existing production facilities.

Marketing

IFDC's marketing training programs are concerned with meeting the fertilizer needs of the ultimate consumer—the farmer. The goal of all marketing programs is to strengthen the ability of the developing-country marketing organizations to implement their activities in a timely, efficiently coordinated manner.

The 1986 schedule contained five fertilizer marketing programs. Two of these programs were conducted at Headquarters and three were presented regionally.

A new program on fertilizer quality control was included in the curriculum. The goal of this program was to provide the participants with a broad knowledge of the factors that influence fertilizer product quality. Such criteria as raw material specifications, process design and plant operation, product types, storage, physical distribution, sampling, physical and chemical analyses, regulation, and management factors were thoroughly explored.

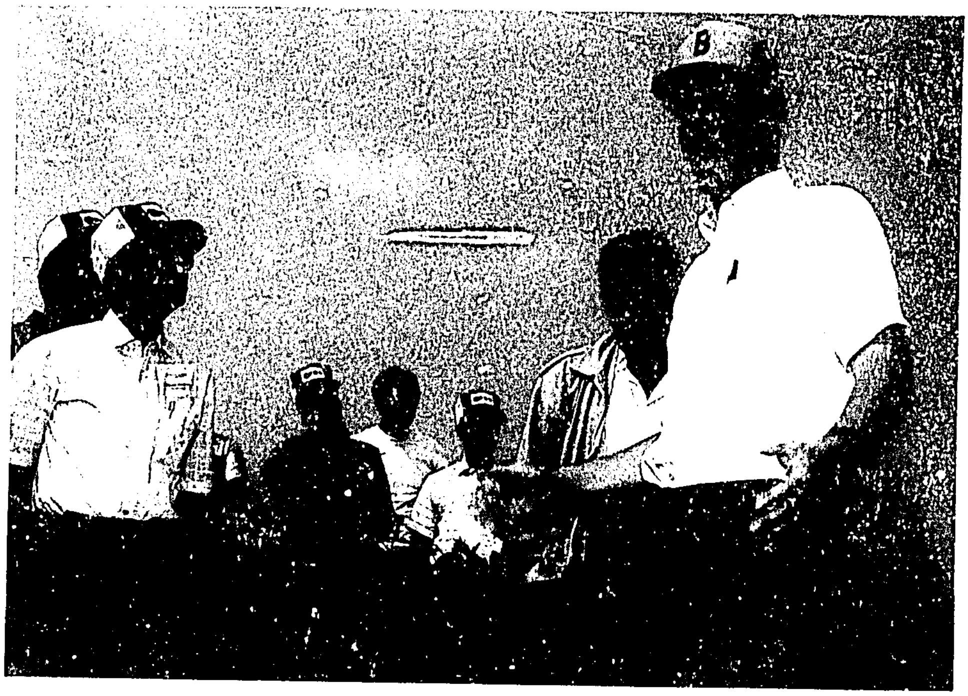
The longest running program, Fertilizer Marketing Management, was presented for the tenth time in 1986. Incorporated in the program were several types of training activities, including lectures, films, simulation exercises, role play, case studies, and panel discussions. The marketing managers gained "hands-on" experience in operating a fertilizer marketing system using IFDC's computer-assisted fertilizer marketing simulation program. In this exercise groups of participants operate competing marketing organizations. Field trips to observe and discuss operations of phosphate mines, fertilizer plants, dealers, and local farms gave a practical aspect to the program.

The regional marketing programs given in 1986 were Fertilizer Distribution and Handling (conducted in India, Indonesia, Malaysia, and Singapore), Regional Fertilizer Marketing (held in Indonesia), and Statistics and Economics of Fertilizer Use (presented at CIAT in Colombia).

Use

One program offered during 1986 focused on fertilizer use efficiency research. This program—Soil Testing and Fertility Management—is presented annually at Headquarters as

Fertilizer handling is demonstrated in India.



Field trips play a very important role in training programs at IFDC. These participants in a marketing management program visit an experiment station in Missouri (U.S.A.).

part of an Auburn University program, which is sponsored by the U.S. Department of Agriculture.

Fertilizer Sector

During 1986 two programs relating to the fertilizer sector were offered; these included: Use of Microcomputers (offered since 1984 and twice during 1986) and a Workshop on African Fertilizer Sector Development.

The new program focusing on the African fertilizer sector was developed with the financial support of UNDP in response to the recognized need for expanding the role of fertilizer in increasing much-needed food production in Africa.

Specialized Training Programs

The specialized training program offerings and participant involvement have increased dramatically over the past few years. In fact, the number of participants involved in specialized training programs has increased from 134 in 1985 to 279 in 1986. In 1985 13 different specialized programs were offered as compared with 27 for 1986. These programs cover a broad range of subjects related to fertilizer production, marketing, and use research as shown in Table 2. About 87% of the 1986 specialized training participants took part in Bangladesh in-country fertilizer marketing-focused training programs conducted by IFDC in support of its Bangladesh marketing and distribution improvement programs sponsored by USAID.

Table 2. 1986 IFDC Specialized Training Programs

Program[a]	Participants: Country	Participants: Number
Fertilizer Marketing Management Two Programs—In-Country	Bangladesh	64
Fertilizer Dealer Training Eight Programs—In-Country	Bangladesh	176
Fertilizer Marketing Study Team	Bangladesh	1
Fertilizer Dealer Development—Bangkok, Thailand	Bangladesh	1
Use of Microcomputers	India	2
Fertilizer Quality Control	Nigeria	3
Fertilizer Production and Testing	Venezuela	1
Fertilizer Research	Venezuela	2
Bulk Handling Fertilizer	India	4
Fluid Fertilizer Production	Brazil	13
Fertilizer Efficiency Research	Swaziland	1
Mali Fertilizer Research	Mali	1
NPK Granulation/Fluid Fertilizer	Brazil	1
Soil Fertility	Pakistan	1
^{15}N Research	Chile	1
Plant Nutrition	Thailand	1
^{15}N Research/Systems Modeling	Malaysia	1
^{15}N Research	Venezuela	1
Fertilizer Technology	Egypt	4
	12 countries	**279**

a. Programs conducted at IFDC Headquarters except as otherwise indicated.

Cooperative Training and Technology Transfer Activities

As noted earlier, IFDC cooperates with and assists other organizations in arranging and conducting their fertilizer-related training and technology transfer programs and often provides subject-matter specialists to serve as lecturers during such programs. Two such 1986 activities merit mention.

In one instance, IFDC supported and assisted in organizing the International Conference on the Management and Fertilization of Upland Soils sponsored by the Chinese Academy of Sciences and the Ministry of Agriculture, Animal Husbandry, and Fisheries of the People's Republic of China. The conference was held in Nanjing and attracted 211 participants. IFDC staff chaired sessions and presented papers at the conference. Additionally, IFDC assisted in arranging funding for 14 delegates representing 14 countries—in Africa (4), Asia (5), and Latin America (5). UNDP and the Australian Development Assistance Bureau (ADAB) participated with other donor agencies in funding these participants.

In the second case, an IFDC Agronomist/Systems Modeler helped to organize and acted as program coordinator for the International Workshop on Systems Analysis and Crop Simulation for Agrotechnology Transfer held in Serdang, Malaysia. The workshop was sponsored by the Malaysian Agricultural Research and Development Institute and the International Benchmark Sites Network for Agrotechnology Transfer with which IFDC has been cooperating. The workshop was attended by 42 participants from Malaysia, Indonesia, Thailand, Philippines, Venezuela, and the United States.

Evaluation

Program evaluation is a continuing process as IFDC strives to improve current training program offerings and develop and introduce new programs and workshops, which respond better to participants' needs to enhance capabilities in various areas of fertilizer sector development and operation. Participants' views as to the relevance and usefulness of currently offered training programs are ascertained from formal program evaluation questionnaires completed at the conclusion of each program. Their reactions to IFDC's 1986 training programs ranged from "very good" to "excellent."

Participants' views are important in determining the required types of training programs, subject-matter emphasis and treatment, instructional methodology, course administration, and venue. In 1986 the new training programs were developed and presented in part in response to the perceived need for such programs. In 1986 increased use was made of guest lecturers from developing countries and participant involvement in class exercises and field trips. The use of computers in fertilizer sector operations continued to attract participant interest.

Special Global Projects

Computer Program for Sizing Rotary Dryers

The design of rotary dryers for the fertilizer industry is usually based on heat balance and calculations of retention time. Normally, conservative data are used in the heat transfer calculations, which result in an oversized dryer that gives good results in processing conventional fertilizers having a high critical relative humidity (CRH), much higher than the relative humidity (RH) of the air leaving the dryer. This, however, indicates that the drying capacity of the equipment is not fully used, leading to a nonoptimum plant design.

In processing fertilizers with low CRH, and particularly those that are sensitive to temperature, as is the case of urea-based fertilizers, the abovementioned dryer design will lead to erroneous results. If the RH of the air is close to the CRH of the product at the dryer outlet, drying conditions will be negligible, and the product discharged from the dryer will be wet.

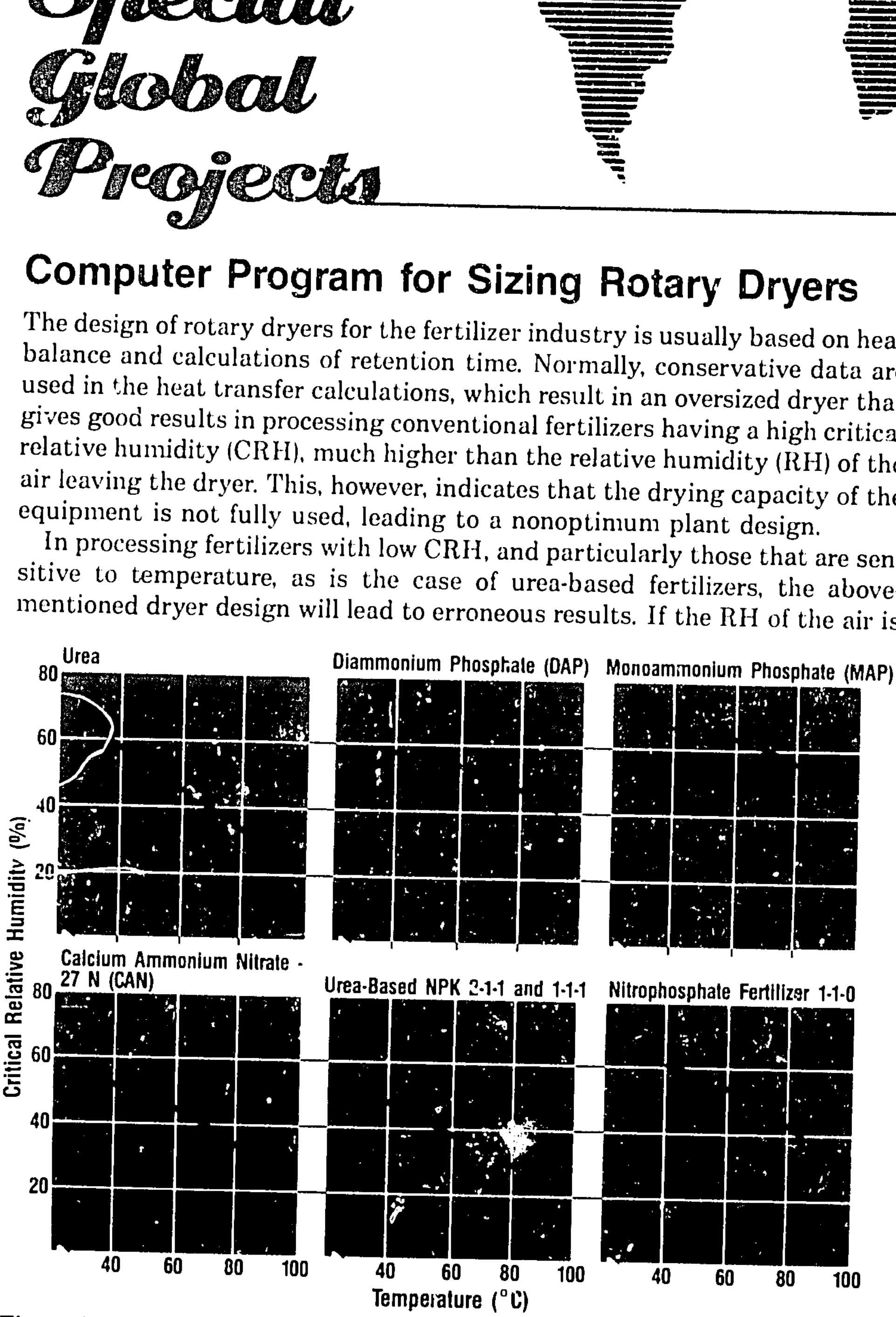


Figure 15. Critical Relative Humidity Versus Temperature Relationship for Various Fertilizers.

To overcome this, a computer program called "ROTDRYER," was developed to size rotary dryers based on the RH and temperature of the air leaving the dryer in combination with the CRH of the material at that temperature. Although originally written for sizing rotary dryers, the program can be used to rate existing equipment, particularly when considering the production of urea-based NPs or NPKs in equipment originally designed for the production of more conventional fertilizers.

The program, originally written in Fortran 77, has been modified for use on microcomputers. It is provided on 5 1/4-inch diskettes, including several secondary programs and files that simplify its use. A printer is not required although its use is highly recommended for keeping records of the solutions calculated by the program.

Included in the software package are program diskettes, an in-depth technical description of the calculations used, and an operating manual that guides the user through all the necessary steps and demonstrates some applications of the program.

ROTDRYER uses information provided by the user, which includes data on ambient conditions and the nature of the material to be dried. A section of the operating manual is devoted to providing guidelines for selecting or calculating appropriate values for this information, such as the CRH of the fertilizer being processed (Figure 15). The program includes a series of default values for all unknown parameters. This computer program is available from IFDC.

Crop Modeling Development and Application

Model Development

Development of the CERES rice model is an ongoing collaborative activity with Michigan State University. Procedures have been developed for simulating water balance under rice crops from those permanently flooded, to those with intermittent flooding, and those grown under upland conditions. Added flexibility has been provided by enabling the model to simulate either direct-seeded rice crops or transplanted rice. Development of procedures to simulate nitrogen transformations under paddy are continued.

Model Applications

The CERES MAIZE model has been used together with a weather generator program to simulate the growth of maize crops and their response to fertilizer in several locations in West Africa. Three very contrasting locations (Table 3) were chosen to examine differing fertilizer practices.

An appropriate planting time for each of these locations was determined through the examination of the generated weather sequences, and other initial conditions pertinent to each of these locations were defined. Several fertilizer use technologies were evaluated for each location. These fertilizer technologies were defined by (1) the rates of fertilizer application varying from 0 to 276 kg nitrogen/ha in 23 kg nitrogen/ha increments applied at planting, (2) a splitting strategy where one-half of the fertilizer was applied at planting and the remainder 30 days after planting, and (3) a second splitting strategy where one-half of the fertilizer was applied 21 days after planting and the remainder at tasseling. For each case the model was run with 50 years of simulated weather data to obtain and examine not only the response to fertilizer but also the variability in response associated with weather variables.

Comparison of rate and timing strategies was made by examining probability distributions for yield, leaching losses, and apparent recovery of fertilizer. The third splitting strategy (one-half applied 21 days after planting and the remainder at tasseling) showed a comparative advantage over the basal application for each of three locations. The results showed that in Burkina Faso where there is also a high probability of crop failure and, in Benin with medium rainfall, there is little difference between the two strategies. However, at the wettest location in Guinea the splitting strategies had a high probability of more favorable outcomes than single basal applications.

Further work is underway to enable the model to identify simultaneously the most appropriate rate and timing strategy under conditions of uncertainty.

Table 3. West African Locations Used in Simulation Study

Location	Country	Mean Annual Rainfall	Soil Type
		(mm)	
Ouahigouya	Burkina Faso	684	Alfisol
Cotonou	Benin	1,495	Ultisol
Conakry	Guinea	4,227	Ultisol

Financial Report

Price Waterhouse

March 12, 1987

To the Board of Directors of
International Fertilizer Development Center

In our opinion, the accompanying balance sheets and the related statements of revenue and expenses and changes in fund balances, of functional expenses and of changes in cash and certificates of deposit present fairly the financial position of International Fertilizer Development Center (IFDC) at December 31, 1986 and 1985, and the results of its operations and changes in its fund balances for the years then ended, in conformity with generally accepted accounting principles consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Price Waterhouse

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

CURRENT FUND

ASSETS

	December 31, 1986	December 31, 1985
Cash	$ 134,800	$ 88,055
Certificates of deposit	962,784	217,939
Amounts receivable from donors (Notes 1 and 2)	2,977,734	3,701,339
Other accounts receivable	1,160,366	709,478
Advances to employees	90,917	68,695
Supplies inventory (Note 1)	136,411	140,223
Prepaid expenses	140,696	125,341
	$5,603,708	$5,051,070

LIABILITIES AND FUND BALANCES

	December 31, 1986	December 31, 1985
Accounts payable	$ 258,684	$ 249,638
Accrued annual and sick leave	1,439,808	1,460,191
Deferred revenue (Notes 1 and 2)	2,975,199	3,443,997
Total liabilities and deferred revenue	4,673,691	5,153,826
Fund balance -		
Restricted	(101,673)	(95,509)
Unrestricted	1,031,690	(7,247)
	930,017	(102,756)
	$5,603,708	$5,051,070

NONCURRENT FUND

	December 31, 1986	December 31, 1985
Amounts receivable from donors (Notes 1 and 2) - restricted	$ -0-	$ 521,236

	December 31, 1986	December 31, 1985
Deferred revenue (Notes 1 and 2) - restricted	$ -0-	$ 521,236

BUILDINGS AND EQUIPMENT FUND

(Note 1)

	December 31, 1986	December 31, 1985
Buildings	$5,814,290	$5,734,995
Equipment	4,687,221	4,782,296
Less - Accumulated depreciation	(5,219,377)	(4,623,116)
	$5,282,134	$5,894,175

	December 31, 1986	December 31, 1985
Contract retainage	$ 421	$ 206
Fund balance	5,281,713	5,893,969
	$5,282,134	$5,894,175

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1986 AND 1985

	Current Fund		Buildings and Equipment Fund		Total All Funds	
	1986	1985	1986	1985	1986	1985
Revenue:						
Grants (Note 2)	$5,903,352	$5,713,652			$5,903,352	$ 5,713,652
Recovered project costs	2,478,424	2,319,147			2,478,424	2,319,147
Other	139,154	97,489			139,154	97,489
Total revenue	8,520,930	8,130,288			8,520,930	8,130,288
Expenses:						
Research	3,523,058	4,513,619	$ 498,916	$ 522,994	4,021,974	5,036,613
Outreach	2,165,872	2,475,997	56,740	45,156	2,222,612	2,521,153
General and administrative	1,760,395	2,157,870	95,432	110,155	1,855,827	2,268,025
Total expenses	7,449,325	9,147,486	651,088	678,305	8,100,413	9,825,791
Excess (deficiency) of revenue over expenses	1,071,605	(1,017,198)	(651,088)	(678,305)	$ 420,517	($ 1,695,503)
Other changes in fund balances:						
Equipment acquisitions from unrestricted funds	(38,832)	(50,954)	38,832	50,954		
Fund balances, beginning of period	(102,756)	965,396	5,893,969	6,521,320		
Fund balances, end of period	$ 930,017	($ 102,756)	$5,281,713	$5,893,969		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1986 AND 1985

	Research		Outreach		General and Administrative		Total Expenses	
	1986	1985	1986	1985	1986	1985	1986	1985
Personnel compensation (Note 3)	$1,892,895	$2,485,879	$1,097,586	$1,249,547	$ 914,872	$1,090,733	$ 3,905,353	$ 4,826,159
Personnel benefits (Note 3)	348,126	434,533	200,628	239,562	177,457	223,417	726,211	897,512
Travel and transportation	260,596	369,605	345,728	426,720	156,947	150,170	763,271	946,495
Occupancy	271,709	252,115	134,598	112,824	135,018	112,879	541,325	477,818
Telephone and telegraph	39,528	42,660	33,240	45,628	23,494	27,167	96,262	115,455
Rental of equipment	9,318	35,119	4,405	24,372	29,550	35,514	43,273	95,005
Contractual research and development	260,835	332,444	45,474	60,435	61,280	36,765	367,589	429,644
Other contractual services	187,899	184,933	163,867	187,068	72,126	159,444	423,892	531,445
Institute of International Education fee (Note 3)					120,930	104,826	120,930	104,826
Materials and supplies	194,648	318,531	97,142	100,941	40,890	188,055	332,680	607,527
Postage	20,893	25,967	20,256	12,983	9,525	12,983	50,674	51,933
Insurance	36,611	31,833	22,948	15,917	18,306	15,918	77,865	63,668
Miscellaneous	7,055	19,152	(1,989)		(3,176)	23,296	1,890	42,448
Total expenses before depreciation	3,530,113	4,532,771	2,163,883	2,475,997	1,757,219	2,181,167	7,451,215	9,189,935
Depreciation of buildings and equipment	491,861	503,842	58,729	45,156	98,608	86,858	649,198	635,856
Total expenses	$4,021,974	$5,036,613	$2,222,612	$2,521,153	$1,855,827	$2,268,025	$ 8,100,413	$ 9,825,791

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF CHANGES IN CASH AND CERTIFICATES OF DEPOSIT

	Years ended December 31, 1986	1985
Balances at beginning of year:		
Cash	$ 88,055	$ 80,279
Certificates of deposit	217,939	1,457,604
	$ 305,994	$1,537,883
Cash was provided by:-		
Excess (deficiency) of revenue over expenses	$ 420,517	($1,695,503)
Charges not requiring (providing) an outlay of cash:		
Depreciation	649,198	635,856
Loss on disposal of equipment	1,890	42,448
Increase (decrease) in accrued annual and sick leave	(20,383)	99,141
Cash provided from operations	1,051,222	(918,058)
Net decrease in receivables from donors	723,605	
Proceeds from sale of equipment	17,354	2,230
Net decrease in other accounts receivable		67,990
Net increase in contract retainages	215	
Net decrease in advances to employees		12,853
Net decrease in supplies inventory	3,812	12,047
Net decrease in prepaid expenses		33,586
Net increase in accounts payable	9,046	3,117
	1,805,254	(786,235)
Cash was used for:		
Purchase of buildings and equipment	56,401	52,978
Net increase in current amounts receivable from donors		113,658
Net increase in advances to employees	22,222	
Net increase in other accounts receivable	450,888	
Net decrease in bank overdraft		135,128
Net increase in prepaid expenses	15,355	
Net decrease in deferred revenue (current fund)	468,798	143,684
Net decrease in contract retainages		206
	1,013,664	445,654
Net increase (decrease) in cash	$ 791,590	($1,231,889)
Balances at end of year:		
Cash	$ 134,800	$ 88,055
Certificates of deposit	962,784	217,939
	$1,097,584	$ 305,994

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

NOTES TO FINANCIAL STATEMENTS

NOTE 1 - ORGANIZATION AND ACCOUNTING POLICIES:-

International Fertilizer Development Center (IFDC) is a non-profit organization incorporated October 7, 1974 under the state laws of Alabama. On March 14, 1977, IFDC was designated as a public international organization by executive order of the President of the United States. The purpose of the organization is to improve fertilizers and knowledge of fertilizer uses in developing countries through research and development, technical assistance and training and communications.

In the event of dissolution, the articles of incorporation provide that the residual assets of the organization will be turned over to one or more tax exempt organizations or to the federal, state or local government for exclusive public purpose.

The accounts of IFDC are maintained on the accrual basis. The following is a summary of significant accounting policies:

A. Buildings and equipment are stated at cost. Depreciation is computed on the straight-line method over estimated useful lives ranging from three to thirty-five years.

B. Grants are recorded as receivable for the full amount at the date of the grant with revenue recognition deferred until corresponding expenses have been incurred. Contributions for reimbursable costs are recognized as project costs are incurred.

Revenue is restricted to the extent it is to be used in accordance with the purpose specified by the grant. Restrictions generally include a specified project or goal within a particular geographic region.

C. Inventories of supplies are valued at the lower of cost or replacement cost, cost being determined on a first-in, first-out basis.

D. IFDC is exempt from federal income taxes as a publicly supported organization under Section 501(c)(3) of the Internal Revenue Code.

NOTE 2 - GRANTS:-

Grants are summarized as follows:

	Years ended December 31, 1986		1985	
	Restricted	Unrestricted	Restricted	Unrestricted
Grants received -				
United States Agency for International Development (AID)		$4,000,000	$ 199,718	$4,000,000
United Nations Development Programme	$ 600,000			
Australian Development Assistance Bureau (ADAB)	65,000	153,318		589,430
International Development Research Centre (IDRC)			192,056	
Rockefeller Foundation	50,000			
Israel Chemical Company		45,000		45,000
	715,000	4,198,318	391,774	4,634,430
Amounts deferred during prior year	1,991,975	1,973,258	2,892,110	1,760,571
	2,706,975	6,171,576	3,283,884	6,395,001
Less - Amounts deferred to future periods	1,024,200	1,950,999	1,991,975	1,973,258
Revenue recognized in current period	$1,682,775	4,220,577	$1,291,909	4,421,743
		1,682,775		1,291,909
Total restricted and unrestricted		$5,903,352		$5,713,652

The unrestricted grants from AID provided funds of $4,000,000 during each of the fiscal years ending June 30, 1987 and 1986. The unrestricted ADAB grants in 1986 and 1985 were gifts of funds recognized as revenue in the year received.

Restricted grants received were restricted by the grantor as to specific projects and/or geographic regions. The IDRC grant in 1985 provided funds for a research project in West Africa, to be completed June 30, 1987. The UNDP grant of $600,000 awarded during 1986 is restricted to use in research and outreach projects in East and Southeast Africa. This grant expires in October, 1987. Any grant funds not expended at the grant expiration date will revert to the grantor.

Receivables from donors at December 31, 1986 and 1985 are summarized as follows:

	December 31, 1986		1985	
	Restricted	Unrestricted	Restricted	Unrestricted
AID	$ 57,576	$1,957,934	$ 271,466	$2,185,000
UNDP	628,367		1,065,000	
IDRC	288,257		655,509	
Ford Foundation		45,600		45,600
	974,200	2,003,534	1,991,975	2,230,600
Less - noncurrent portion			(521,236)	
	$ 974,200	2,003,534	$1,470,739	2,230,600
		974,200		1,470,739
Total restricted and unrestricted		$2,977,734		$3,701,339

Of the UNDP total, $268,367 relates to a grant providing funds for various research and outreach projects for grant periods of more than one year. This UNDP grant expires in 1987; consequently, all funds relating to this grant receivable are classified as current at December 31, 1986.

NOTE 3 - INSTITUTE OF INTERNATIONAL EDUCATION:

IFDC has a contract with the Institute of International Education (IIE) whereby all payroll administrative functions are performed by IIE; IFDC makes advances monthly to fund salaries, employment taxes and fringe benefits.

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(as of December 31, 1986)

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Jimmy Waddell, Training Aide*
Lewis B. Williams, Regional Coordinator—Africa

*Left in 1986.
**Retired in 1986.
***Deceased.
****Extended Leave.

International Fertilizer Development Center
P.O. Box 2040
Muscle Shoals, Alabama 35662 U.S.A.

Phone No. 205-381-6600
TWX-810-731-3970 IFDEC MCHL

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