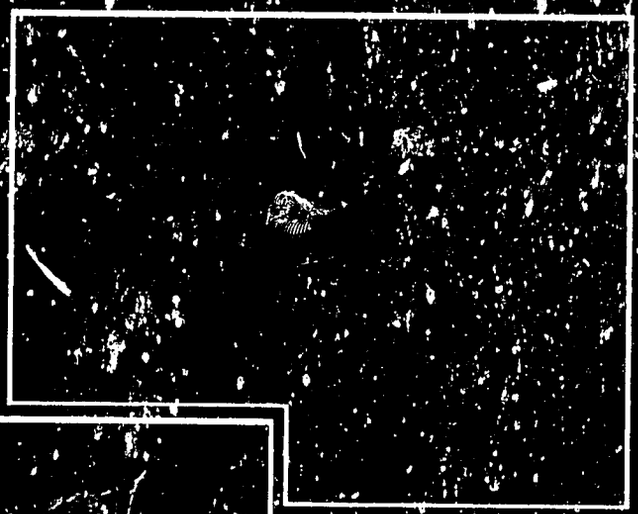
PN-ABB-857 ISN 99 4

International Fertilizer Development Center

Annual Report 1985



"Many of the threads of a tapestry depicting the year 1985 would surely portray the famine in Africa. There is hope for Africa's future, and IFDC is involved in that brighter destiny."

IFDC on the African Scene

Cameroon

In early 1985 the Center offered its first fertilizer efficiency research and technology transfer workshop, which was held in Cameroon.

An IFDC team also visited that country to study its fertilizer sector and suggest improvements in its fertilizer marketing, use, and supply systems.

Here, Cameroon agricultural workers examine nutrient deficiency in maize.

Kenyan workers harvest groundnuts.

Kenya

Later in the year a marketing team helped Kenya devise a plan to remove some of the constraints to fertilizer use that country encounters.

Mali

Moving next to Mali, the Center continued a national program, which was initiated 5 years ago, to help the Malian people take a valuable resource, phosphate rock, and use it as a fertilizer to produce more food.

Malian women grinding grain.

This young Nigerien girl sells her wares in an open market.

Niger

In Niger, as well as several other countries—Burkina Faso, Gambia, Ivory Coast, Malawi, Senegal, Sierra Leone, Tanzania, Uganda, Zambia, and Zimbabwe, to name a few—IFDC's scientists are working side by side with national scientists to find ways of economically using fertilizers in general and more specifically of using indigenous materials for phosphate fertilizers to increase food production.

A Nigerian woman sells yams at a farmer's roadside market. In Nigeria most of the crop harvesting and marketing is carried out by women.

Nigeria

At the request of the Federal Republic of Nigeria, IFDC sent a team of marketing specialists to that country to conduct commercialization and transportation studies of its fertilizer sector. The marketing and distribution plans that resulted are being translated into savings and benefits for Nigeria.

IFDC's Managing Director (third from left) and Togolese officials conduct the initial surveying of the site of the IFDC-Africa Center.

Togo

Togo was the site of a symposium, which revealed the results of a 3-year research program on nitrogen and phosphorus management conducted by the Center in some 17 countries of sub-Saharan Africa.

During 1985 the Government of Togo signed an agreement with IFDC to help the Center create a greater presence in Africa by establishing a regional center there. The Togolese provided IFDC with land for the facility and granted it international immunities and privileges.

Management Report

If a craftsman were to weave a tapestry depicting the year 1985, it is certain that many of its threads would portray the famine in Africa. Much of its surface would be dappled with the somber colors of hunger, suffering, and death of innocent people. But what can be done to change the picture and prevent similar crises from recurring in the future?

If fertilizers had been playing their rightful role, many who died during the recent food crisis as well as those who suffered so much need not have done so. We at IFDC commit and dedicate ourselves to do all in our power to not let famine happen again because of a lack of proper fertilizer use. We realize that the only long-term solution to the food problem in Africa is to increase domestic food production and decrease population growth and urbanization rate.

A bright ray of hope does exist to help formulate and implement this solution. That ray of hope originates with the international agricultural research centers that are helping Africa find ways to increase its food production through the use of the basic building blocks of agricultural development—improved seeds, fertilizer, irrigation, insecticides, pesticides, effective extension services, reasonable pricing policies, and rural infrastructure.

Since IFDC was created, the Center has strived to increase food production through improved fertilizers and fertilization practices in Latin America, Asia, and Africa. Many countries of Latin America and Asia have since achieved self-sufficiency in food production. Thus, in those regions, the need for IFDC's assistance has become more specific and highly focused while that of Africa is more concerned with total fertilizer sector development. Because of the urgency of Africa's situation, IFDC has made a very positive commitment to the alleviation of hunger on that continent. Since its inception in 1974, the Center has strived to create a greater presence in its mandate area, the tropics and subtropics. Toward this end, in 1985 the Government of Togo agreed to help IFDC establish a regional center in Africa by providing land for the facility and granting it international immunities and privileges. Plans are underway for establishing the IFDC-Africa Center; donor support to build the necessary infrastructure and staff is being sought. It is hoped that staff will be posted in that country by late 1986. The Lomé Center will have major responsibilities in technology research and development, training, and technical assistance.

The vital role that fertilizers play in increasing food production has been well documented. According to the Food and Agriculture Organization of the United Nations, "fertilizers can unlock dramatic increases in productivity. Proper use of appropriate fertilizers could increase yields by 50%-60% in developing countries. A ton of fertilizer often translates into 10 or more tons of grain."

Because Africa imports most of its fertilizer at a relatively high cost, it uses the lowest level of fertilizer nutrients in the world. One of IFDC's goals is to help African countries use their own resources for fertilizer wherever that is economically and technically feasible.

Approximately 20 African countries have mineral resources that can be used to produce phosphate fertilizers needed to increase food production; others have potash and sulfur resources. IFDC has conducted evaluations of raw materials for some 20 countries in Africa. At least 10 countries have natural gas that could be used to produce nitrogen fertilizer. In addition, there is a wealth of human resources to be developed into scientists, engineers, and other problem solvers.

Since 1979 IFDC has been involved in Africa; the Center has provided training for people from 30 African countries, strengthened national programs, and provided technical assistance to some 20 countries. In 1981 the Center began its formal field research in Africa; staff members have been stationed in Niger and Nigeria. The IFDC research network is currently working with scientists in Benin, Burkina Faso, Cameroon, Gambia, Ghana, Ivory Coast, Kenya, Liberia, Malawi, Mali, Niger, Nigeria, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Zambia, and Zimbabwe in a cooperative effort to find ways of economically using fertilizers in general and more specifically of using indigenous materials for phosphate fertilizers.

When the IFDC regional center in Africa becomes a reality, much more can be done to help the African people feed themselves. After all, the only aid that has lasting value is that which prepares a nation to solve its own problems and to produce much of its food on a sustained basis through agricultural and economic development. By helping African nationals develop appropriate technologies that can increase their food production, we will be providing long-term solutions that are needed to conquer hunger, malnutrition, and disease. In the long run, it is more economical to "feed the crops that feed the people than to feed the people through food aid."

In other words, if you give a man a cup of rice, he can eat today, but if you teach him to grow rice, he can eat for a lifetime—that is, if he can find the land on which to grow it.

Donald L. McCune
Managing Director

Paul J. Stangel
Deputy Managing Director

Contents

Research Programs

Bio[illegible]

S[illegible]

[illegible] Research

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Asia

Latin America

Training Programs

Group Training

Individual Training

Evaluation

Financial Report

Board of Directors

Staff

F Rudolph

Research Program

IFDC's research program has a four-pronged emphasis: nitrogen, phosphate, sulfur, and economics. During 1985 significant advances were realized in each of these areas.

The IFDC nitrogen program is focused on ways to avoid wastage of N through proper targeting and use of N fertilizer. When we consider the fact that every percentage point of wasted N carries with it a price of US $25-50 million (depending on the current price of N), we can easily recognize the importance of this program. In 1985 IFDC continued research in a wide range of agroecological environments, ranging from the risky climes of the Sahel to the breadbasket of India, the Punjab. Researchers at Headquarters continue to look for chemical and physical modifications of urea that will make it a more efficient source of N.

The notion of using indigenous resources where possible to fill the fertilizer needs of developing countries is rapidly taking root. IFDC continues to visit various countries to assess the potential of their phosphate deposits and identify ways to modify the rock if direct application does not seem feasible. Although the science of partial acidulation of any type of rock has been mastered in our laboratories and pilot plants, research continues on finding ways to render phosphate rock more available without chemical processing. Management of directly applied phosphate rock and admixtures with solubilizing substances are but two of the routes being explored. However, the partial acidulation technology proved attractive enough for one Indian company to initiate construction of a plant while Niger and Colombia are in the process of making such decisions.

The sulfur program at IFDC was significantly accelerated in 1985. The need for such a program is being brought home by experimental results showing a lack of response to other nutrients if S is not supplied. Although the full extent of S deficiency in the tropics and subtropics is yet to be assessed, studies are being initiated to identify a means of returning some S in high-analysis fertilizers while evaluating them in some environments known to be S deficient; ^{35}S is used to trace the fate of applied S.

The economics program of IFDC is aimed at providing the essential know-how on farmers' attitudes toward this input in the research environments as well as conducting the ultimate analysis of the pros and cons of fertilizer practices. The farmers' survey approach was expanded in 1985 to include the semiarid tropics in India. The evaluation component was significantly strengthened through the development of the Fertilizer Evaluation Program and Information System (FEPIS). Through development of new software, this team is now able to readily assess the IFDC agro-economic database and perform analyses by crop, ecological zone, or country. Simulation modeling allows for extrapolation of field results.

The 1985 results of the research program are but a single frame out of a motion picture; however, if mirrored against the frozen frame of previous years, the progress being made becomes clear.

Nitrogen Research

As in previous years, low efficiency of fertilizer N continued to be a serious concern of our N program. The current level of N use in the developing world is estimated at 29 million tons annually. Nitrogen uptake by rice does not reach more than 20%-40% of that applied. Efficiencies on upland crops are more variable but can match the figures quoted for rice. A second concern of IFDC is that fertilizer N is used in those areas where soil and climatic conditions are favorable for profitable use. With the great variability of agroecological conditions in the tropics and subtropics, responses to N are highly variable as well.

We further explored the means to make N more efficient so that farmers of the developing world can get maximum value from its use. Our earlier

research on several occasions has consistently confirmed the superior performance of urea supergranules (USG) for lowland transplanted rice. We, however, have been hesitant to recommend its adoption by the farmer due to a very high labor demand associated with hand deep placement of USG. This problem was partially solved by the development of a simple USG dispenser with transplanting guide, which reduces labor requirement for USG placement by 33% or more as compared to traditional methods used in countries such as India.

The search for chemical compounds that inhibit urease activity yielded encouraging results. Phenoxyamino-substituted cyclophosphazenes exhibited lower initial inhibition, but it was sustained over a longer period. Another urease inhibitor N-butylthiophosphoric triamide (NBTPTA from Allied Chemicals) successfully checked the buildup of ammonia concentration in the floodwater—an important prerequisite for volatilization loss of fertilizer N. NBTPTA appears to be more powerful than the well- known phenylphosphorodiamidate (PPD). Research continues to assess its benefits in the field.

Denitrification like ammonia volatilization can be a serious N loss mechanism in some soils. Wide variations in nitrification (an inevitable basic step of denitrification) capacity of soils suggested that denitrification will not pose the same degree of gaseous loss of N from all soils. A notable achievement was the development of technology for measuring the gaseous products of denitrification accurately.

One-time application of urea formaldehyde and guanyl urea sulfate to lowland rice produced yields similar to the researchers' recommended split of urea. The practice of draining floodwater 1 day before N application followed by reflooding 3 days after application proved inferior. The slight yield increase with PPD was also not significant when compared with researchers' recommended split. Urea amended with PPD, no doubt, reduced the volatilization loss.

In the drylands of Senegal, point placement of USG (100 kg N/ha) yielded almost 1 ton of additional maize grain compared with the farmer's practice of spreading urea (100 kg N/ha) on the soil surface. Point placement, however, failed to maintain its superiority in the dry, sandy soils of the millet zone of Niger. We are delineating areas and cropping systems in which point placement will be an effective strategy to improve yields.

In the Mediterranean-type environment, urea was an efficient N source for wheat grown on heavy-textured soils. Losses of N did not exceed 10% when the fertilizer was placed in bands or incorporated in the soil after application. Loss from topdressed N was also low.

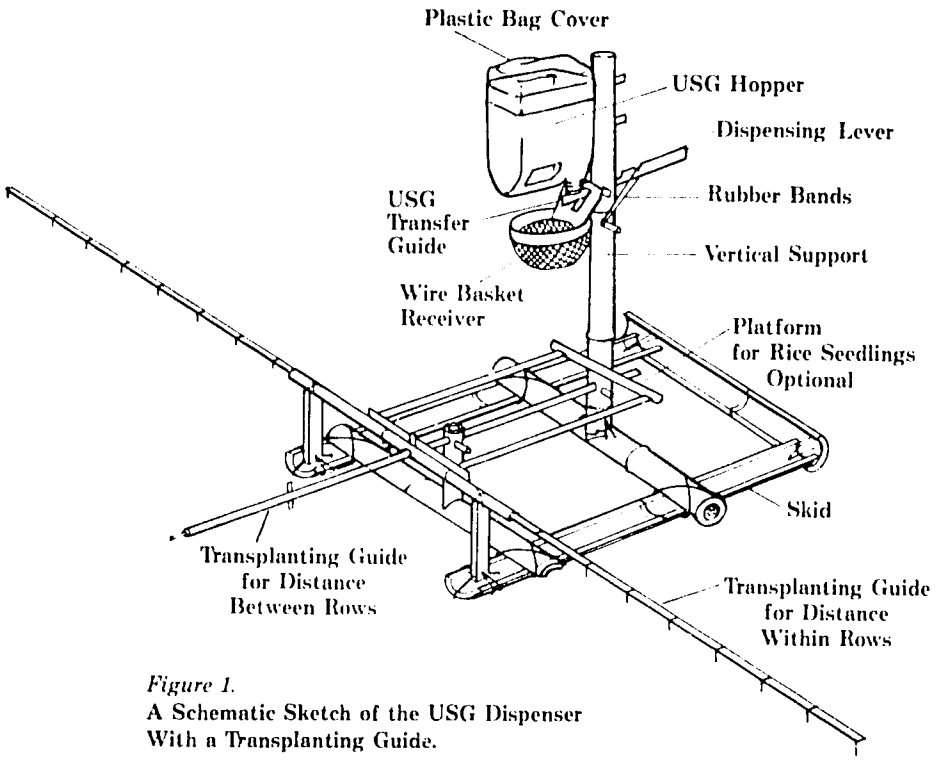


Figure 1.
A Schematic Sketch of the USG Dispenser With a Transplanting Guide.

Indian field workers use the USG dispenser in a rice paddy at transplanting time.

In the Indian semiarid tropics in high rainfall years, loss of urea N from shallow Vertisols was greater (29% versus 6%) than that from deep Vertisols. Leaching appeared to be a dominant loss mechanism since N loss became still greater when potassium nitrate replaced urea. Along with the soil depth, rainfall had a profound influence on the N use efficiency. Fluctuations in rainfall had little effect on the efficiency of fertilizer N on deep soils, while increasing rainfall reduced it on shallow soils.

Materials for Improved Efficiency

Urea Supergranules

The improved N use efficiency achieved by deep placement of USG on paddy rice under Asian conditions is so well documented that the Center has phased out agronomic research on USG at Headquarters. However, research was continued in certain national programs, and findings there substantiate earlier results as reported in the literature.

Although the deep placement of USG is an efficient way of applying urea fertilizer to wetland transplanted rice, the technology cannot be used by small rice farmers in the developing countries at present mainly for two reasons: (1) Deep placement of USG by hand a few days after transplanting is a very labor-intensive operation. (2) At present, there is no commercial production and supply of USG.

In an effort to combine the hand deep-placement operation with transplanting, a device called a "USG dispenser with transplanting guide" was developed at IFDC Headquarters. This dispenser was then fabricated of bamboo and other locally available materials (Figure 1) at the Mahatma Phule Agricultural University at Pune, India. Field evaluation trials conducted during the 1985 wet (Kharif) season in India show that by using the USG dispenser with transplanting guide, labor required for deep placement can be reduced by 33% or more of that required for deep placement done by hand a few days after transplanting. The device is inexpensive (US $3-4), light-weight ($\cong$2.5 kg), simple in design, and easy to use. Transplanted seedlings are not disturbed. Various shapes of urea particles can be used.

USG is a nonconventional N fertilizer because of its individual granule size and/or shape. If USG is produced commercially a prime concern is its physical handling and storage characteristics. For this reason, granular (spherical) and briquette (pillow-shape) forms were analyzed for weight loss during handling. Bulk density, angle of repose, granule crushing strength, abrasion resistance, impact resistance, handling strength, and caking tendency are routine tests performed on fertilizers.

The test results show that: (1) the use of a conditioner, such as formaldehyde, is apparently necessary to reduce excessive USG granule breakage during handling; (2) the process of briquetting produces a USG that is prone to excessive fines and dust formation; (3) the pan-granulation process apparently produces the best USG with respect to handling and storage properties; (4) all USG tested was especially susceptible to excessive granule breakage upon impact; and (5) caking does not seem to be a significant problem with USG.

Chemically Modified Urea

The very high losses of N through ammonia volatilization when urea is applied to flooded rice have continued to be a major concern of our scientists. Such losses were as high as 50% of the applied urea under actual field conditions in the Philippines. Although urea applied at a 6-10 cm depth in the soil is taken up very efficiently by rice under most circumstances, it is difficult to place the fertilizer at this depth. IFDC scientists are therefore continuing work on urease inhibitors that will reduce ammonia volatilization losses without requiring the farmer to change his fertilizer application methods. This research is supported in part by the

IFDC Chemist, B. W. Biggers, examines USG produced on a tableting machine.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). The project is a joint effort of IFDC and Tennessee Valley Authority (TVA) scientists.

Effects of PPD—The urease inhibitor PPD has been by far the most effective chemical used to block the enzymatic conversion of urea to ammonia in flooded soil systems. IFDC scientists have shown that by maintaining the urea as urea and preventing its hydrolysis to ammonia, volatilization losses can be decreased considerably. Although plant uptake of N applied as urea has been increased by 15%-20% by using PPD in both greenhouse and field studies, it has not increased rice yields except in a few cases. Since PPD has not been shown to have adverse effects on the rice plants, it is believed that the lack of a favorable yield response has been due to the fact that PPD degrades in a few days, thereby allowing urea hydrolysis to proceed rapidly after 3-4 days following the urea application. IFDC scientists are therefore searching for urease inhibitors that have a more sustained inhibition than PPD and for ways to slow the degradation of PPD in soil systems.

Research conducted earlier at Headquarters in water solutions with the pH buffered with phosphate ions indicated that two mechanisms of PPD degradation occur, depending on the pH of the solution. The slowest rate of

B. H. Byrnes, Research Associate, conducts studies of urease inhibitors.

degradation occurred at slightly acidic pH (about 6.0). As the solution became either more acidic or more basic, the rate of PPD degradation increased dramatically. However, when PPD was put into soils, the rate of degradation was from 2 to 50 times faster than that predicted from the pH of the soil alone. Biological degradation was shown to not be a major factor contributing to the degradation, since the degradation rate was not much different in heat-sterilized versus unsterilized soils. This led to work involving the effect of different concentrations of ions on the rate of PPD degradation.

In solutions kept at a constant pH by addition of acid or base, it was found that the addition of common salts could greatly increase or decrease the degradation rate of PPD, depending on the pH of the system and what ions were added. These two phenomena (the rapid degradation of PPD in soil and the effects of other ions) were taken into consideration when the treated urea was applied to flooded soil systems. The disappearance of PPD from the floodwater could be altered by the addition of common salts, and the maintenance of PPD in the water resulted in better performance of PPD as a urease inhibitor. Addition of triple superphosphate (TSP) and copper sulfate decreased the degradation of PPD and maintained urea in the floodwater for a longer time. The slow disappearance of urea in the presence of the inhibitors is thought to be due to urea uptake by algae, rather than hydrolysis of urea, since little ammonia was detected in the water until the inhibitor failed and a rapid decrease in the urea concentration occurred.

New Inhibitors—During 1985 intermediates and products for urease inhibition were isolated and purified by various techniques, such as fractional distillation, extraction, recrystallization, and preparative-scale high-performance liquid chromatography (HPLC). The compounds were characterized by elemental analyses, infrared spectroscopy, nuclear magnetic resonance spectroscopy, and HPLC analyses. Emphasis was placed on a class of compounds known as phosphazenes (P-N compounds). Three compounds (phenoxyamino-substituted cyclophosphazenes) exhibited various degrees of sustained urease inhibition in soils. More highly substituted compounds provided a lower initial inhibition, but it was sustained over a longer period.

The urease inhibitor NBTPTA was very stable in the floodwater and worked very well as a urease inhibitor. With the addition of this compound, there were no appreciable amounts of ammonia in any of the treatments at any time. This compound has been patented by Allied Chemical Corporation as a urease inhibitor and appears to be more powerful than PPD. Research will continue at Headquarters and in tropical field studies to assess the benefit of using urease inhibitors and to assess the soil conditions under which the greatest benefit can be achieved.

Headquarters' Agronomic Research

Nitrogen research at Headquarters includes the testing of experimental fertilizer materials in soils with different properties and under a range of simulated climatic conditions, as well as research to support field programs primarily in Africa and Asia.

During 1985 this work concentrated on the further testing of urease inhibitors, studying the mechanism of ammonia volatilization in upland soils, evaluating the nitrification potential of rice soils, and developing an analytical technique for the direct measurement of gaseous forms of N formed upon denitrification.

Ammonia Volatilization

The fate of urea applied to medium- to light-textured soils was studied in relation to the method of fertilizer application and the pretreatment of the soils. Losses of N due to ammonia volatilization were highest when urea was applied to the surface of soils that had been dry for several months and wetted just prior to fertilizer application. Most of the losses from surface-applied urea occurred shortly after application, but they continued for several weeks (Figure 2). Incorporation of urea reduced N losses regardless of pretreatment of soils and appeared to be the most important factor in reducing N losses (Table 1).

Nitrogen losses were lowest when urea was incorporated into soils that had been kept moist (field capacity) for at least 2 weeks prior to the fertilizer application. Preincubation of the moist soils increased the rate of nitrification of ammonium formed upon hydrolysis of urea; this resulted in significantly lower ammonium concentrations in the preincubated soils and thus in lower partial pressures of the ammonia.

It was concluded that applying fertilizers to the dry soils before the start of the rainy season, as is practiced in some semiarid regions may be risky if rains do not arrive within the following 2 days. Earlier research showed that a 2-3 cm rainfall practically eliminated ammonia loss. Fertilizer application after the start of the rainy season, when the nitrifying bacteria population has established itself, may thus be a more efficient way of applying urea fertilizer.

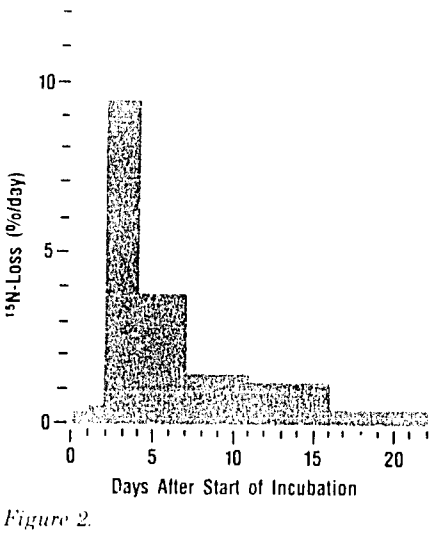


Figure 2.
Nitrogen Loss From Surface-Applied Urea as a Function of Time After Start of Incubation.

Denitrification

Fertilizer N applied to soils will be transformed under oxidizing conditions to nitrates (nitrification). When the rate of oxygen consumption by micro-organisms in soils exceeds the rate of oxygen supply, reducing conditions may develop under which nitrates are transformed into the gaseous products, nitrous oxide and nitrogen (denitrification). Dentrification can be a major N loss mechanism in soils where the oxygen supply is limited. This applies to permanently flooded soils, such as in wetland rice systems, but may also apply to upland soils after heavy rainfall. In view of the potential importance of N losses due to denitrification, it is important to understand the nitrification as well as the denitrification dynamics in soils

A study of the nitrification potential (measured through the conversion of ammonium to nitrate N) in rice soils showed that soil pH plays an important role in determining the nitrification potential/capacity of these soils. Urea in soils with a pH of 5.5 or less either nitrified very slowly or did not nitrify at all. This information will be useful in identifying soils where denitrification losses may present a problem. In case of the soils that nitrified quickly, the rate of nitrification depended on the concentration of ammonium-N. This suggested that nitrification was a first-order reaction under the conditions of the experiments and would thus be limited by the concentration of ammonium ions in the soil-water system.

To distinguish denitrification from other loss mechanisms, it is essential to measure directly the denitrification products, N and nitrous oxide. To distinguish denitrified N from the atmospheric N, fertilizer containing a high level of ^{15}N must be used. Directly measuring a mixture of denitrification products on a dual-collector mass spectrometer has been a costly and difficult process.

Methods of Determination—IFDC researchers have developed a new indirect method for measuring the ^{15}N content of a mixture of N and oxygen gases. The method uses a high voltage arc to redistribute the N isotopes and to fix part of the N as oxides of N species. The oxides of N formed are then reduced to ammonia, distilled, and prepared for ^{15}N analysis. The ^{15}N can now be analyzed by the routine method using a dual-collector mass spectrometer.

The other major denitrification product, nitrous oxide, has also been studied. Nitrous oxide is very unstable in the arc process. Therefore, if nitrous oxide is present in a sample, it is rapidly converted to N by the arcing process. Subsequently, the arc fixes part of the N as oxides of N, which can be chemically converted to ammonia and processed as a routine ^{15}N sample.

This method has been successfully tested by arcing simulated samples containing ^{15}N-nitrogen and ^{15}N-nitrous oxide in air. IFDC scientists are modifying this method so that it can be used to measure denitrification in greenhouse and field experiments.

Table 1. Losses of Nitrogen From Urea Applied to Soils

	^{15}N Losses (%)	
	Incorporated	Surface-Applied
Precincubation	5.3	34.2
Nonpreincubation	10.4	46.9

Statistical Analysis

Linear model: F = 81.35*** $\bar{R}^2$ = 0.966

-Type of application: F = 440.85***
-Incubation: F = 32.78***
-Application X incubation: F = 5.75*

Wetland Nitrogen Program

Field research conducted in IFDC's field program at the International Rice Research Institute (IRRI) in 1985 was focused on identification and evaluation of strategies to overcome N losses due to ammonia volatilization thereby

increasing the portion of added N fertilizer available for use by rice The evaluated strategies included slow-release N sources, urease inhibitors, and water management.

Slow-Release Nitrogen Sources

IFDC chemists recently developed a simplified process for manufacturing urea-formaldehydes (ureaforms) for use as a slow-release N fertilizer. Experimental ureaforms with either 5% or 10% paraformaldehyde (PFA) added to urea were field evaluated.

Guanylurea sulfate, an experimental slow-release N source, was also evaluated because of promising results previously obtained in greenhouse tests.

The amount of N fertilizer volatilized as ammonia depends on the concentration of ammonia gas in the floodwater. Ammonia gas in the floodwater increases with increasing ammoniacal-N concentration, pH, and temperature. Partial pressure of ammonia in the floodwater can be used to compare relative ammonia loss for different N sources.

Addition of paraformaldehyde to urea reduced floodwater ammonia and thus may reduce ammonia volatilization loss. Guanylurea sulfate was very effective in reducing floodwater ammonia. The very low partial pressure of ammonia resulted from low concentration of ammoniacal N in the floodwater and a suppression of the pH of the floodwater after application of guanylurea sulfate.

Rice responded to application of ureaforms and guanylurea sulfate (Table 2). Grain yield without applied N was 2.9 tons/ha. Yield with the two ureaforms, all broadcast and incorporated before transplanting, was comparable with that for the researchers' recommended split of urea. Yields with ureaform and prilled urea were significantly less than with deep-placed USG. Grain yield was not significantly lower for guanylurea sulfate than for USG.

Uptake of N by the rice plant was much greater with N fertilization (Figure 3). Uptake of N was greatest with USG and slightly more with ureaform and guanylurea sulfate than with prilled urea. Uptake of N was comparable for the ureaforms with 5% and 10% paraformaldehyde.

Urease Inhibitors Under Wetland Conditions

The inhibitor PPD has been shown to delay urea hydrolysis and reduce subsequent buildup of ammoniacal-N in the floodwater. The effectiveness of PPD in reducing N loss and increasing grain yield was assessed for three timings of N application. Urea with and without 1% PPD was broadcast into the floodwater at either 18, 28, or 38 days after transplanting. PPD was effective in reducing N loss as determined by the ^{15}N balance. The added ^{15}N-labeled urea not recovered in the plant and soil, and presumably lost as N gases, was significantly less with PPD than without it at 2 and 4 weeks after N application (Table 3). N loss tended to decrease as the time of application was delayed. Unfortunately, the reduced N loss with PPD did not result in increased grain yield.

Since PPD does not completely eliminate N losses as indicated by the unrecovered ^{15}N for the application 18 and 28 days after transplanting (Table 3), the search for a more effective urease inhibitor was continued.

Photosynthesis by algae is associated with a marked rise in the pH of the floodwater and this converts part of the ammonium ions to ammonia and subsequently causes loss of ammonia to the atmosphere. Field research at IRRI showed that the amendment of urea fertilizer with an algicide effectively controlled algal biomass and prevented a buildup in floodwater pH immediately following urea application. Even though floodwater ammoniacal-N increased with the algicide treatment because of reduced as-

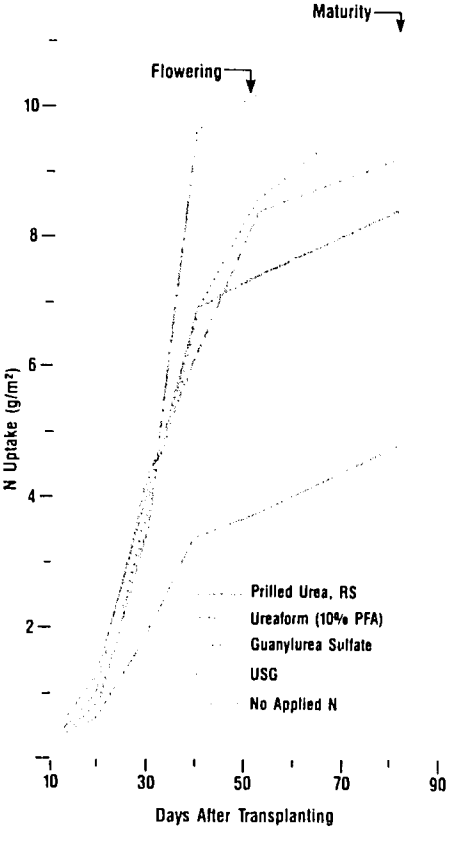


Figure 3.
Influence of Nitrogen Sources on Uptake by IR58, Pila, Laguna, Philippines, 1985 Dry Season.

Table 2. Influence of Nitrogen Source on Grain Yield Response of Rice

Nitrogen Source[a]	Grain Yield[b]			
	58 kg N/ha	87 kg N/ha	116 kg N/ha	Mean
	(tons/ha)			
Prilled urea, RS	4.4 ab	4.8 b	5.5 a	4.9 b
USG, DP	4.9 a	5.6 a	5.8 a	5.4 a
Ureaform (5% PFA), B & I	4.3 b	5.0 b	5.4 a	4.9 b
Ureaform (10% PFA), B & I	4.3 b	5.0 b	5.5 a	4.9 b
Guanylurea sulfate, B & I	4.8 ab	5.1 ab	5.5 a	5.1 ab

a. RS = researchers' split (2/3 broadcast and incorporated without standing water, 1/3 5-7 days before panicle initiation); DP = deep placement; B & I = broadcast and incorporated; PFA = paraformaldehyde.
b. In a column, means followed by a common letter are not significantly different at 5% level by Duncan's Multiple Range Test.

similation, the ammonia level in the floodwater was dramatically reduced (Figure 4). The lower partial pressure of ammonia in the floodwater indicates reduced ammonia loss in the presence of an algicide.

Water Management

Draining the floodwater, broadcasting urea onto a saturated soil, and then reflooding (macak-macak in Indonesia) is common in continuous flow irrigation schemes. Little is known about N losses with such a practice and whether it could be an effective alternative to broadcasting urea into floodwater of irrigated rice where N runoff is not a problem.

Field trials conducted at IRRI examined the practice of draining floodwater 1 day before N application, applying urea to saturated soil, and then reflooding 3 days after application relative to broadcasting urea or urea with 2% PPD into 5 cm of floodwater (Table 4). Two-thirds of the N was applied 18 days after transplanting and one-third 5 to 10 days after panicle initiation. The practice of draining the floodwater proved inferior; grain yield was significantly reduced. The slight yield increase with PPD was not significant.

Table 3. Effect of PPD and Timing of Nitrogen Application on the Unrecovered ^{15}N, Presumably Gaseous Nitrogen Loss at 18 and 28 Days After Nitrogen Application

Treatment	Time of N Application DAT)	Unrecovered $^{15}N^a$ 18 Days	28 Days
		(%)	
Urea	18	35 a	34 a
Urea + 1% PPD	18	16 b	18 b
Urea	28	16 b	20 b
Urea + 1% PPD	28	8 c	6 c
Urea	38	12 bc	8 bc
Urea + 1% PPD	38	0 d	2 c

a. In a column, means followed by a common letter are not significantly different at 5% level by Duncan's Multiple Range Test.

Note: DAT = days after transplanting.

Table 4. Influence of Nitrogen Rate and Treatment on Grain Yield of Rice

	Grain Yield (tons/ha)
N rate (R)	
0	3.9
30 kg N/ha	4.8
60 kg N/ha	5.8
90 kg N/ha	6.4
120 kg N/ha	6.7
N treatment (N), average yields of 4 nonzero N rates	
Urea, 5 cm water (N_1)	6.0
Urea + 2% PPD, 5 cm water (N_2)	6.2
Urea, saturated soil (N_3)	5.5

Analysis of variance:

Source	Mean Square
N rate (R)	16.350**
0 versus treated	40.646**
Among treated	8.251**
N treatment (N)	1.497**
N_1 versus N_2	0.184^{ns}
N_3 versus N_1, N_2	2.810**
R x N	0.222^{ns}

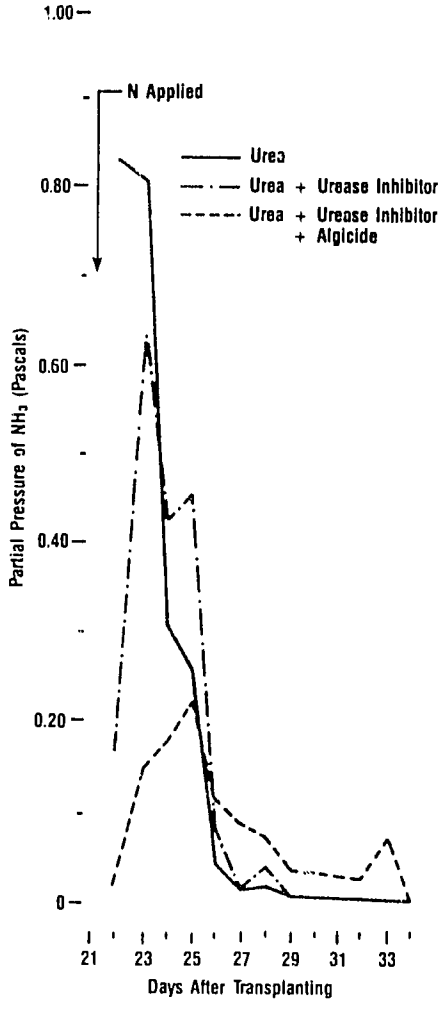


Figure 4.
Effect of Algicide on Partial Pressure of Ammonia at 1400 Hours.

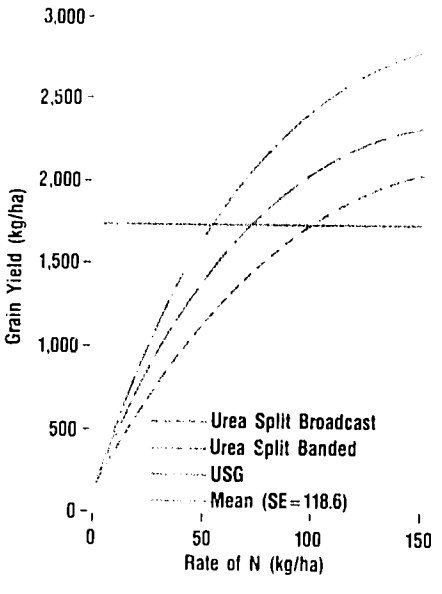
Upland Nitrogen Program

The upland N program is conducted in sub-Sahara Africa and in west and south Asia. The program is concentrated on the major cereal food crops grown in the semiarid subtropics (wheat and barley) and in the semiarid tropics (maize, sorghum, and millet).

Sub-Saharan Africa

Since 1982 IFDC has been working in conjunction with national scientists from 14 countries to study and improve the efficiency of N fertilizers in Africa. This program, though funded originally by the International Fund for Agricultural Development (IFAD), is presently funded by the International Development Research Center (IDRC) of Canada and the U.S. Agency for International Development (USAID).

Because of the limited funds available to him, the African farmer tends to base his purchases of fertilizer not on the basis of how much the plant needs but rather on how much he can afford to spend. Assuming that this monetary limit to fertilizer use will continue, the objective of the West African Fertilizer and Fertilizer Management Evaluation Network (WAFFMEN) has been to improve the efficiency of those limited amounts of fertilizer purchases by the farmer.



Source: F. Ganry, ISRA, Senegal.
Figure 5.
Nitrogen Management Trial: Senegal, 1984, Maize Grain Yield.

It is recognized that urea is rapidly becoming the single most commonly imported N source in west Africa, and work has therefore been concentrated on improving its efficiency. All collaborators working within the WAFFMEN program follow similar experimental outlines with similar crops so that comparison across regions can be achieved. Presently, the program focuses on the effect of placement on N uptake and response.

In many countries farmers apply urea by spreading it on the soil surface (broadcasting) and then incorporating it during weeding. Field trials were established where this practice is compared with the application of the N in a band 6-8 cm deep near the plant row and point placement of all the N required for each plant at a depth of 6-8 cm near the plant. Though involving more labor, the point placement technique has resulted in substantial yield increases in some cases.

Data from Senegal illustrate this trend (Figure 5). Point placement significantly increased maize yields over those obtained when urea was banded or broadcast and incorporated. Studies using ^{15}N show that N losses were reduced from 36% when urea was broadcast to 5% when N was point placed. This resulted in increased amounts of N available for plant growth and grain production.

This positive trend was not followed in the dry, sandy soils of the millet zone of Niger. In that region, point placement of urea showed little improvement over broadcasting. Further work by members of this network will help define those areas and cropping systems in which point placement may become an effective strategy to improve yields.

Mediterranean Region

N fertilizer research was conducted in Syria in cooperation with the International Center for Agricultural Research in the Dry Areas (ICARDA) at Aleppo, Syria. During the 1983/84 and 1984/85 growing seasons (November-May), N balance trials were conducted with wheat at two experimental sites in Northwest Syria, Tel Hadya, and Breda. Urea fertilizer was applied to the wheat crop in a split application: 20 kg N/ha mixed with the seed at planting in late November and the remainder (0, 20, or 40 kg N/ha) as a topdressing in early February.

Previous research had shown that incorporation of fertilizer at planting was an efficient way of applying urea; this practice reduced losses of N due to ammonia volatilization to less than 10% of the N applied.

A topdressing of N in early February is considered to be an important management tool for the farmer to maximize his yield since most of the rainfall is generally concentrated in the winter months. Thus, the farmer would be able to match the amounts of N to be topdressed to his yield expectations: more N in a season with above-average rainfall and little or no N in a below-average season.

Little was known about the losses of N from urea topdressed in early February, but it was suspected that losses due to ammonia volatilization could be considerable and thus affect fertilizer efficiency. In order to investigate this point further, several N-balance trials were conducted in which ^{15}N-labeled urea was topdressed to wheat grown at Tel Hadya and Breda. Data from these trials show that rainfall was a major factor determining total dry-matter yields of wheat grown at these locations although there was some response to applied N in all trials. In the trial with the lowest rainfall (Tel Hadya, 1983/84) yield increased by 50% between the lowest and the highest level of N application. Rainfall, however, increased yields in unfertilized plots from 2.4 to 6.8 tons/ha, that is, nearly tripled the yield from one season to the other.

In three trials for prilled urea applied as a topdressing to wheat in early February at a rate of 40 kg N/ha, fertilizer N recoveries in the soils and the crops were measured. The losses of N were calculated by the difference from the known amounts of N applied and the ^{15}N recoveries in the soil and the crop. Previous research had shown that

nitrate-N topdressed in late winter was fully recovered at harvest; this suggests that denitrification and leaching are of minor importance in these soils in late winter and spring. Therefore, it is assumed that ammonia volatilization was the major loss mechanism; N losses ranged from 11% to 18%. Total recoveries in the soil plus the crop were similar in all trials, but the distribution between the plant and the soil was significantly affected by seasonal rainfall. The fertilizer recovery in the crop was highest in the highest rainfall trial.

The general conclusion of the research was that urea appears to be a rather efficient N fertilizer for the heavy-textured soils in northwest Syria. Losses of N applied at planting are expected to be low (5%-10%) when the fertilizer is placed in bands with the seed or otherwise incorporated in the soil. Losses of N applied as a topdressing are expected to be low (in the range of 10%-20%) because of the high clay content of the soils involved, which keeps the solution concentrations of ammoniacal N low and thus reduces the potential for ammonia volatilization.

Semiarid Tropics

Fate of Fertilizer N on Shallow Black Soils of Semiarid Tropical India—In semiarid tropical India, black soils are known to be very important in food production. These soils are high in clay content and thus high in moisture-holding capacity compared with other soils. There are two types of black soils: deep black soil known as Vertisol and shallow black soil known as Vertic Inceptisol. The areas of these two soils are roughly identical, with approximately 27 million ha each. In an earlier stage of this project, studies were started on deep black soil and then later expanded to shallow black soils. As shown in Table 5, the behavior of fertilizer N in these two soils is remarkably different. During years with above-average rainfall (>550 mm) on shallow black soil, the recovery of applied N was much lower (36% versus 56%), and the loss was greater (29% versus 6.1%) than on deep black soil. The fact that the loss of applied N was much greater when N was applied as potassium nitrate than when it was applied as urea in these shallow black soil under excessive rainfall suggested that the low efficiency and high loss of applied N were due to loss via leaching. These results suggest that on shallow black soils in above-average rainfall years or when they are subjected to occasional high-intensity rainfalls typical for the semiarid tropics, the use of slow-release N fertilizer such as sulfur-coated urea may increase the recovery by the crop and reduce the loss of fertilizer N. The use of urea treated with nitrification inhibitors and application of the fertilizers in a greater number of splits also may help to accomplish these objectives. These treatments should be included in such trials.

Results of 5 years of experiments with sorghum at the ICRISAT Center revealed that rainfall profoundly influences the effect of urea on the N uptake. But the influence of rainfall on the efficiency of urea varied for the different soils. As is shown in Table 6, the apparent recovery of urea in the deep Vertisols is not greatly affected by the amount of seasonal rainfall, ranging from 60% to 71%. However, the shallow black soils show an increase in apparent recovery with decreasing rainfall. Leaching beyond the root zone may be the cause of poor recovery in wet years on the shallow soils. These results indicate that different fertilizer application technologies may be needed to improve the N fertilizer efficiency on different soils or the same soils with different rainfall patterns.

Table 5. Recovery by Crop and Loss of Fertilizer Nitrogen on Deep Black Soil (1981, Rainfall 907 mm) and Shallow Black Soil (1983, Rainfall 913 mm) in Rainy Season Sorghum (CSH6) Crop at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center, Patancheru, India

	Deep Black Soil	Shallow Black Soil	
	Urea	Urea	KNO_3
N applied (kg/ha)	74	60	60
N recovery by crop (%)	55.7	36.3	34.8
N in soil (%)	38.2	34.6	23.4
N loss (%)	6.1	29.1	41.8

Table 6. Apparent Recovery (%) of Urea by Improved Cultivars of Sorghum (CSH 6) in Different Rainy Seasons on Black Soils in Semiarid Tropical India

Season[a]	1981	1982	1983	1984	1985
Rainfall (mm)	630	417	603	412	308
Apparent Recovery (%)					
Black soil					
Deep	61.8	71.3	60.3	-	64.0
Shallow	-	-	31.8	51.3	78.5

a. Rainy season: June-August.

Phosphate Research

The phosphate research program at IFDC has been focused on development and evaluation of techniques through which developing countries can convert indigenous deposits or low-cost raw materials of phosphate rock to cost-effective forms of fertilizer. The IFDC organization allows for unique interdisciplinary interaction in this endeavor. In 1985 IFDC scientists and engineers combined their efforts to obtain new technical information on ore beneficiation techniques, acidulation processes, nonconventional as well as conventional granulation methods, mechanisms influencing P reactions in soils, and management practices most appropriate for fertilizers produced from the indigenous ores.

It is well known that the mineralogy and chemistry of phosphate ores vary significantly from deposit to deposit. IFDC Headquarters facilities, which include modern laboratories, pilot plants, and greenhouses, are used to characterize the differences between diverse ore samples, develop appropriate process parameters for fertilizer production, and conduct initial screening of experimental fertilizers. The evaluation of modified ores is being continued for the most promising test products through field research programs in the tropics and subtropics. These field programs are conducted collaboratively with scientists of national and international institutions located in Africa, Asia, and Latin America, as well as IFDC staff outposted within these environments.

IFDC economists, statisticians, and social scientists conduct research critical to the interpretation of engineering and agronomic findings in the phosphate program and provide insight into research needs for the future. Working together the multidisciplinary teams can provide the information to facilitate the decision-making process within national programs regarding alternative uses of their indigenous P resources.

Phosphate Rock Modifications

Beneficiation

Some type of beneficiation is usually required for a phosphate ore if it is to be used in a conventional way to produce fertilizer. The use of the ore and the impurities in it primarily dictate the level of beneficiation required. Since beneficiation requires an investment and an operating cost, it is always necessary to try to minimize these costs. There are several potential ways of doing this: (1) using the simplest effective process, (2) minimizing the consumption of chemicals, and (3) substituting chemicals available in developing countries. IFDC monitors research of other organizations and primarily conducts laboratory tests seeking new and improved ways to beneficiate problem ores. The Center's core-funded activities are concentrating on the two main impurities, silica and carbonates. Samples are chosen to represent a wide variety of ores although each ore can present special difficulties. During 1985 studies were made on some processes for removing silica and carbonate by flotation.

An ore from India containing both silica and carbonate was subjected to heavy-media separation and flotation. The run-of-mine ore contains 18.0% P_2O_5, 15.5% silica, and 35%-38% calcium carbonate. With heavy-media separation using a magnetite suspension followed by two-stage cationic-anionic flotation, a concentrate containing about 27% P_2O_5, 9% silica, and 10% calcium carbonate was obtained. The P_2O_5 recovery was about 75%. Beginning in 1986 IFDC will assist a company in India in using the ore for fertilizer production.

Partial Acidulation

IFDC is making progress in transferring technology on partially acidulated phosphate rock (PAPR) to developing countries. During 1985 the results of several years of process development and agronomic research on sulfuric acid-based partially acidulated phosphate rock (SAB-PAPR) were described in a technical bulletin entitled *Sulfuric Acid-Based Partially Acidulated Phosphate Rock—Its Production, Cost, and Use.* Examples of rocks used from 14 different sources were given. They were chosen to represent several different deposits in developing countries. The Center also performed studies comparing the use of phosphoric or sulfuric acid with selected rocks. Limited tests were also made using both sulfuric and phosphoric acids for acidulation of a selected rock.

Partially acidulated phosphate rock can be made through two processes—run-of-pile (ROP) and granular. The ROP product is semigranular and less dusty compared with the finely ground rock feed. Granular product is more expensive to produce, but it is the least dusty and the additional cost may be justified for blending with other materials or for machine application in some countries. Cost savings are realized in PAPR through three main factors: lower acid consumption, higher output, and lower plant investment for

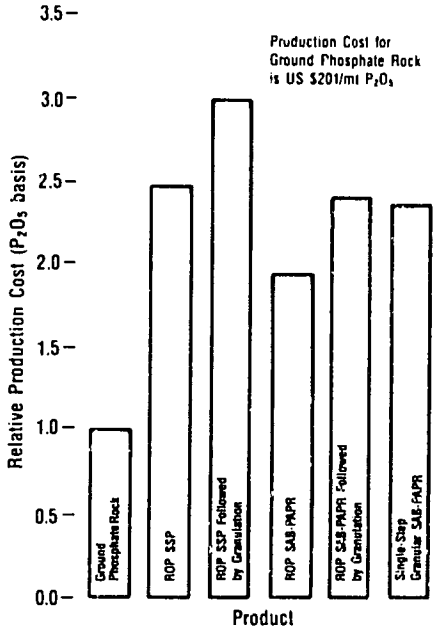


Figure 6.
Relative Production Cost of SAB-PAPR Compared With Alternative Phosphate Products.

T.A.B. Lawendy, Minerals Engineer, conducts beneficiation tests in an IFDC laboratory.

ROP product. Compared with making single superphosphate, only about one-half of the sulfuric acid is required for producing PAPR. The ROP process is very simple; it requires no product drying or recycle equipment. Thus, countries are considering the installation of the ROP process initially with the possible later addition of granulation equipment. The ROP process is especially adaptable to small phosphate deposits in developing countries to serve a local market. Countries such as India, Colombia, Burkina Faso, and Niger are making progress towards using the technology. IFDC is prepared to supply process technology and assist in plant startup and operation.

Figure 6 depicts the cost of SAB-PAPR as compared to other products. Comparative agronomic data from research plots and farmers' fields show that SAB-PAPR is comparable with single superphosphate (SSP) and TSP on acidic soils and those having a high phosphorus-fixation capability.

Studies of Wet-Process Phosphoric Acid

IFDC continues to improve its research capability to process ores to intermediates and finished products. Modifications were made on the continuous bench-scale wet-process phosphoric acid unit to improve the temperature and feed control systems. The unit was operated in the dihydrate mode using central Florida phosphate rock to verify unit operation. A wide variety of ores or concentrates can be evaluated for their suitability for use in making filter-grade (28%-30% P_2O_5) acid. A corresponding concentration unit is used to produce merchant-grade (52%-54% P_2O_5) acid.

Further tests were made in the pilot plant to make 40%-42% P_2O_5 acid directly by the hemihydrate mode. Central Florida and North Carolina phosphate rocks were used. Operational results obtained compared favorably with those reported from industrial-scale processes. Interest in hemihydrate acid production is growing because of its improved energy efficiency. The product acid can be used directly to produce ammonium phosphates without further concentration. IFDC is well equipped to demonstrate the technology of production of wet-process phosphoric acid and to advise developing countries on processing to finished fertilizers.

Nitrophosphate Fertilizers

Interest in nitrophosphate fertilizers is apparent in developing countries since NP or NPK fertilizers can be made without sulfur (sulfuric acid). The phosphate rock is reacted with nitric acid, and the resultant slurry is ammoniated to a solid. The calcium in the rock is removed by precipitation with sulfate; the sulfate ion can be regenerated by reaction of gypsum with ammonium carbonate. Thus, the raw material requirements are phosphate rock, ammonia, nitric acid, and carbon dioxide. A typical solid product contained 26% N and 14% P_2O_5 with most of the P_2O_5 being water soluble. Thus, the IFDC pilot plant employing pug mill granulation was suitable for demonstrating the sulfate precipitation type of nitrophosphate process.

Processes for Producing Multinutrient Fertilizers

Conventional Granulation

Conventional granulation means that raw materials or intermediates (solids, liquids, or gases) are combined in the presence of a liquid phase to produce homogeneous granular fertilizers. Except in the case of melt granulation, a dryer is required to remove moisture. IFDC can simulate many processes, such as: (1) granulation of phosphate rock, (2) partially acidulated phosphate rock run-of-pile (ROP), mono- and diammonium phosphate (MAP and DAP), (3) ammonium phosphate-based NPK, and (4) single and triple superphosphate (SSP/TSP). Product can be made at rates of 20 kg/h up to 1,000 kg/h. Modifications are made to the units to provide process flexibility.

The small unit (20 kg/h) is often used to prepare products for agronomic testing overseas and to conduct projects for clients. Partially acidulated phosphate rocks were produced from ores mined at Huila, Colombia; Hahotoe, Togo; Bayovar, Peru; and Tahoua, Niger, for agronomic tests. Some ex-

ploratory tests were made to incorporate elemental sulfur into superphosphate- type fertilizers. Hazards involve fire and explosion; however, methods are being evaluated to minimize these. It is expected that in the future sulfur will be required in many countries, and better ways of supplying it in fertilizer are needed.

Work has begun on the installation of a fluidized bed in the larger pilot plant. This equipment is recognized as being more energy efficient for certain applications, such as drying and cooling. Processes are commercially available for making granular urea in a fluid bed, but little is known about making multinutrient fertilizers by this method.

Compaction Granulation

Compaction granulation is achieved by pressing one or more solid dry materials into a continuous flake followed by controlled breakage of the flake to produce granules. In a well-run process, off-sized materials are all recovered and recycled. It uses less energy than a wet granulation process because drying and cooling are not required. Some IFDC studies conducted in cooperation with industry show that compaction is more economical than water/steam granulation of dry materials. It can also be used to complement a bulk-blend plant since it can granulate the off-specification material to a form suitable for bulk blending. It is not expected to economically compete with a bulk-blending plant because of much larger investment and higher operating cost.

Using a rather small laboratory machine having inherent limitations, IFDC has made numerous compaction studies of a wide variety of raw materials. During 1985 emphasis was placed on compaction of SSP. Due to its residual moisture and free acid, it becomes thixotropic and difficult to feed to the compactor. In some exploratory tests it was found that ammoniation of SSP (4%-5% N) prior to compaction essentially eliminated all problems. The ammoniated SSP should also be compatible for compaction with urea to make an NP granular product. More tests are planned to overcome the special problem of SSP compaction.

T. E. Evers, Technical Aide, inspects granular PAPR produced in the laboratory-scale granulation unit.

Headquarters' Agronomic Research

Phosphorus Soil Test

IFDC scientists have been working on a new approach to soil analysis for plant-available phosphorus which should be equally as effective with low-solubility P fertilizers as with the conventional high-solubility sources. In 1985 tests were expanded to include greenhouse correlations in addition to the laboratory evaluations. The new method, referred to as the P_i soil test, measures the release of plant-available P from the soil by shaking a soil sample in suspension in the presence of an iron-impregnated paper strip that adsorbs the P from solution. The paper is then removed, and the adsorbed P is measured after being extracted with dilute acid.

Since the objective of the P_i soil test is to provide reliable estimates of plant-available P across a wide range of conditions, 1985 greenhouse tests evaluated the correlation between plant response to P and F_1 levels when maize was grown on five different soils fertilized with two types of P-containing fertilizers applied at three rates of application. The soils ranged in pH from 4.5 to 8.2, and the P was supplied either as TSP or central Florida phosphate rock. The correlation coefficients indicate that the P extracted by the P_i soil test prior to planting was significantly correlated with the dry-matter yield and P uptake of the maize plants. When compared with six other soil test procedures, the precision of the P_i soil test was surpassed only by the resin extraction method. Because the P_i soil test is easier to perform than the resin method, it holds potential for use in areas with high diversity in either soils and/or types of fertilizers being used.

Evaluation of Partially Acidulated Phosphate Rock

Research on PAPR in the past has resulted in highly variable findings. In the 1960s one group of scientists concluded that 20% PAPR (using H_3PO_4) was equally as effective as TSP while another group concluded that plant

response was directly correlated with the water-soluble fraction of the PAPR and that little benefit was obtained from the unacidulated portion. These contrasting observations were difficult to reconcile, but it has been suggested that the differences might possibly be explained by the contrasting experimental conditions used by the two groups.

In an attempt to resolve some of these differences, a greenhouse experiment was conducted that was designed to allow for direct comparison of some key variables. Treatments were included that encompassed the degrees of acidulation, the rates of application, the physical form of the PAPR, and the P-retention capacity of the soils used in the earlier research. The results obtained in this trial tended to support the conclusion that plants respond to both the water-soluble and water-insoluble fractions of the P in the PAPR. The data illustrated in Figure 7 show that, when plotted against only the water-soluble portion of the fertilizer, plant response was improved dramatically through the use of the PAPRs as compared with TSP. This would suggest that the additional response was due to uptake of P from the non-water-soluble portion of the PAPR. Additional measurements showed that the effectiveness of PAPR was maximized when granulated, regardless of whether it was applied to a soil with high or low P-retention capacity. The soil utilized retains approximately one-third of the water-soluble P applied to it.

With the recognition of the high potential of PAPR for use in tropical agriculture, questions also arose regarding the management of this source. One question of particular concern relates to the effect of lime applications on the P availability from PAPR. It is well known that the rate of dissolution of unacidulated phosphate rock decreases as the pH of the soil to which it is applied increases. Liming of acid soils in conjunction with the use of soluble phosphates such as TSP, however, generally enhances the response to P due to a general improvement in the availability of other required plant nutrients and a reduction of soluble aluminum and/or manganese, which may be toxic. Since the P in PAPR is present to varying degrees both in a soluble form and as unacidulated phosphate rock, it was not clear which of the cpposing mechanisms would dominate and thus determine the role of liming with PAPR.

A greenhouse experiment was established, therefore, in which both TSP and Pesca PAPR (Colombia) produced with only 20% of the phosphoric acid required for TSP was applied at rates of 0, 50, 100, and 200 ppm of P to soils that had been treated with five different levels of lime. Maize was then planted and grown for 5 weeks to measure the response to P from the two P sources; the pH of the soils prior to planting was 4.8, 5.6, 6.8, 7.4, and 7.8 as a result of the lime applications. As shown by the results illustrated in Figure 8, the highest yields were obtained with both sources when the soil had been limed to a pH range of 5.6-6.8, and the effectiveness of both sources declined substantially as the rate of lime increased above that point. The mean relative agronomic effectiveness of the PAPR under these greenhouse conditions was found to be 48%, 60%, 61%, 57%, and 46% with increasing rate of lime. These preliminary results indicate that liming recommendations can be expected to serve equally as well with PAPR as with soluble P sources.

Some researchers are now convinced that fertilizers produced with only 50% of the acid required for superphosphates can be substituted for superphosphates without a reduction in agronomic effectiveness, especially in soils with high P-retention capacity. A number of questions remain, however, regarding mechanisms that can explain why the plant is able to use the unacidulated portion of the PAPR to a greater degree than is observed with the use of unacidulated phosphate rock alone. Research was initiated in 1985, therefore, in an attempt to provide information on these mechanisms.

Explanations regarding the release of plant-available P from PAPR have, in the past, focused exclusively on the chemical reactions between water-soluble P and phosphate rock components of the fertilizer in the soil. The approach used in 1985 experiments, however, was to evaluate the role of the "starter effect," which results from the fact that a portion of the P in PAPR is in a water-soluble form. To measure this influence, maize plants were grown in soils that were treated with 0, 50,

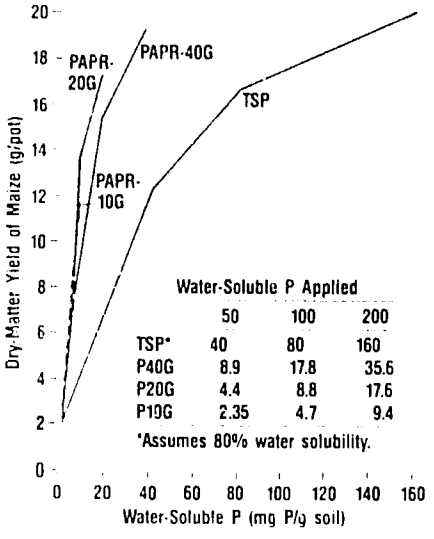


Figure 7.
Maize Response to Water-Soluble Phosphorus From TSP and PAPR.

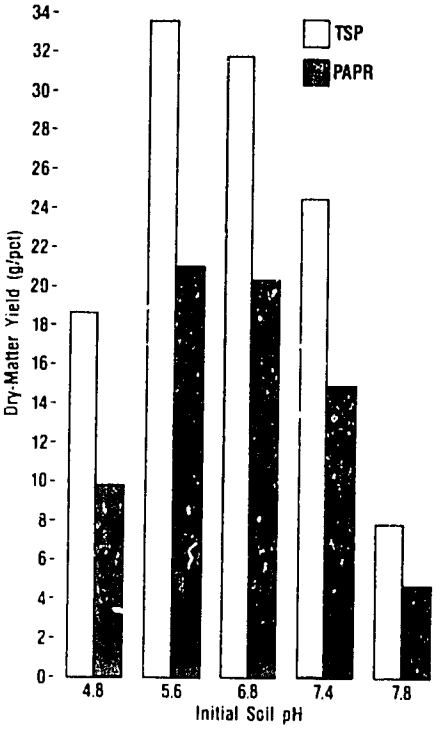


Figure 8.
Influence of Liming on Maize Response to Phosphorus From TSP and PAPR.

100, and 200 ppm P from soluble TSP as well as a treatment with 200 ppm P from central Florida phosphate rock. Two weeks following germination, the plants were removed from these treatments and transplanted into soil that was uniformly treated with 200 ppm P from the central Florida phosphate rock. The plants were then allowed to grow for an additional 30 days. Despite the fact that all plants were extracting P only from the phosphate rock during the last 30 days of growth, large differences were observed in their growth rates during that time. Figure 9 illustrates the influence of having water-soluble P present during the very early stages of growth on the capacity of the plant to use P from the phosphate rock. Further studies are being initiated to verify whether this starter effect was due to expanded root development, increased metabolic activity, or a combination of the two factors.

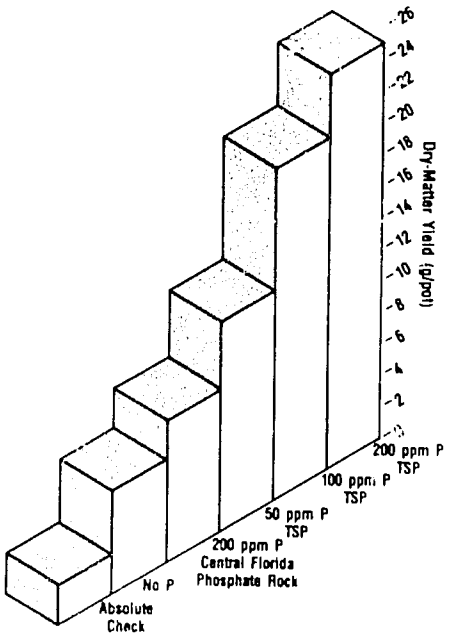


Figure 9.
Influence of Water-Soluble P During First Two Weeks (All Treatments Included 200 ppm P From Central Florida Phosphate Rock for Last 30 Days of Growth Except for Absolute Check).

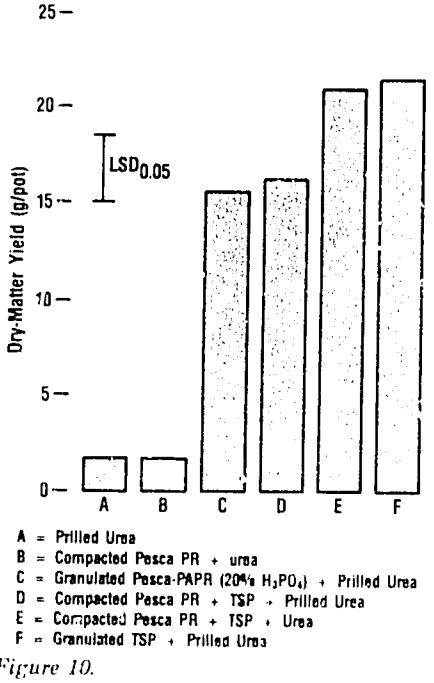


Figure 10.
Dry-Matter Yield of Maize Obtained With Various Phosphate Fertilizers (-6 +14 mesh) in a Short-Term (6 weeks) Greenhouse Experiment. PAPR = Partially Acidulated Phosphate Rock, PR = Phosphate Rock.

One alternative to the use of partially acidulated low-reactivity rock to obtain the necessary starter effect is to compact the rock with urea and soluble phosphates such as TSP. In 1985 IFDC soil scientists conducted a greenhouse study in which the agronomic effectiveness of various combinations of compacted Pesca phosphate rock (a low-reactivity rock) and TSP with urea was compared with that of Pesca-PAPR. In the comparison, compacted phosphate rock + TSP and PAPR had the same granule size (minus 6- plus 14-mesh) and water and citrate solubilities. The results (Figure 10) show that compacted phosphate rock + TSP and PAPR were equally effective in increasing plant yield when prilled urea was used with both fertilizers. Compacted phosphate rock + urea performed poorly and was similar to the check. When the Pesca rock and TSP were compacted with urea, however, the product was more effective than either compacted phosphate rock + TSP or PAPR, and it was not significantly different from TSP. Note that in this study the plant yield obtained with TSP was still increased to 35 g per pot at a fertilizer application rate of 200 ppm of P. These results are encouraging since compacting phosphate rock and TSP with urea not only can improve P availability of phosphate rock but also can supply the N that is required by many tropical acid soils. Field trials using these types of products are planned for the future.

Agronomic Field Research— Latin America

IFDC's agronomic program on P use in Latin America was redirected in 1985 to address problems identified in the 2-year on-farm trials described in the 1984 annual report. As previously reported, it has been observed that indigenous phosphate rocks can, under some circumstances, serve as a highly effective and low-cost means of fertilization when directly applied in a finely ground form. The recent on-farm trials, however, confirmed that in cropping systems typical of the Andean highlands, the agronomic performance of the phosphate rock can be consistently improved when the rock is partially acidulated. Figure 11 illustrates the added economic returns calculated for varying P treatments used in potato experiments conducted in the Ipiales region of Colombia. These results suggest that, since full acidulation is not required, means other than partial acidulation may also be effective in improving the performance of the phosphate rock which may be accomplished by the farmer himself. Investigations on possible alternatives were therefore initiated by IFDC staff stationed at Centro Internacional de Agricultura Tropical (CIAT) in Palmira, Colombia, with the aim of providing small farmers of the mid- and high- altitude tropics of the Andean region (through Instituto Colombiano Agropecuario [ICA]) with recommendations on the most cost-effective use of indigenous phosphate rocks.

Recognizing the diversity of phosphate rock characteristics, soils and cropping systems within the region, a research network was formed to facilitate evaluation of the alternatives across a wide range of conditions. The network was formalized at a workshop at CIAT in May 1985, which was attended by representatives from national institutions in Bolivia, Colombia, Costa Rica, Ecuador, Mexico, and Peru and is supported financially by IDRC of Canada. It was agreed during the workshop that the

most promising approaches to increasing the effectiveness of the local phosphate rocks included (1) further studies on the time and method of application as influenced by soil properties and crop requirements, (2) use of the phosphate rock as a soil amendment followed by fertilization with soluble sources, (3) use of mixtures of the phosphate rock with materials such as organic manures to promote solubilization, (4) use of mixtures of the phosphate rock with other fertilizers readily available to the farmer, and (5) identification of the most appropriate means of partial acidulation for each of the phosphate rock sources. In addition to the agronomic factors, it was also agreed that studies were necessary to identify and analyze economic policy options available to encourage the use of indigenous phosphate rock sources and to assess the potential benefits to the small-farm sector as well as the benefits and costs to the nation as a whole.

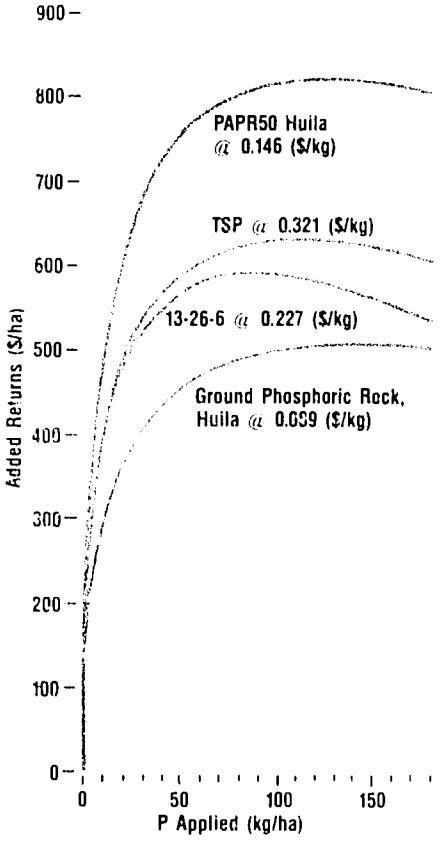


Figure 11.
Added Economic Returns Calculated for Varying Phosphorus Treatments Used in Potato Experiments Conducted in the Ipiales Region of Colombia.

A Colombian farmer, collaborating with the IFDC/CIAT Phosphate Project, cultivates land prior to planting.

As a result, IFDC posted an economist at CIAT to initiate the economic studies. The agronomic investigations were initiated by both the IFDC staff at CIAT and the national collaborators throughout the region. In Colombia, for example, 27 experiments were carried out on the approaches described earlier with crops including beans, maize, cassava, pastures, wheat, potatoes, and sorghum. Data from these experiments will subsequently be combined with data generated throughout the network to answer both agronomic and economic questions related to the influence of pH, P-retention capacity, time and method of phosphate rock incubation with manures, time and method of application, and other variables influencing the viability of using phosphate rock in the region. The agronomic studies being conducted within the network are, therefore, being concentrated on fertilizer materials and fertilizer management considerations.

A project using a third approach to increase fertilizer efficiency in the Andean Region of Latin America was also initiated in 1985. An IFDC specialist in plant physiology was stationed at CIAT in Colombia to study the potential for selecting varieties for improved efficiency of P use by beans (Phaseolus vulgaris).

Research has pointed out the need for identification of key processes and periods of crop development among varieties that exhibit differences in performance under low P conditions. Preliminary results suggest that more than one factor is involved in P efficiency. Plant uptake of soil and fertilizer P at very low concentrations in the soil, more efficient transport of P from the roots to the upper portions of the plant, continued active P uptake during flowering and a higher pod set may all be involved. Research will be continued to clarify which processes are most important and to identify genetic lines that represent extremes in one or more of these efficiency-related characteristics to be used as parents in a breeding program.

Agronomic Field Research—Asia

During the period 1982-84, IFDC conducted a series of studies on the production of modified products from

the low-grade Mussoorie phosphate rock from India. It was concluded from both the laboratory and greenhouse evaluations of these products that partial acidulation with either sulfuric or phosphoric acid showed high potential for expanding the current use of the Mussoorie phosphate rock. As a consequence, IFDC collaborated with Pyrites, Phosphates, and Chemicals, Ltd. (PPCL) in the design and analysis of field experimentation on the P availability of the most promising of the Mussoorie phosphate rock products. In collaboration with scientists from PPCL, Orissa University in Bhubaneswar, Birsa University in Ranchi, and C. S. Azad University in Kanpur, India, IFDC researchers conducted field trials in 1985 with rice-pulse and rice-wheat rotations to determine the relative agronomic effectiveness of the experimental fertilizers. The fertilizers were applied to a variety of P-deficient soils ranging in pH from 5.8 to 7.9, and both initial and residual P availability was measured.

Results obtained in the field investigations confirmed the predictions from the preliminary greenhouse results that PAPR produced from Mussoorie phosphate rock was in general as effective as products with higher water solubility in all experiments. These findings were true for wheat grown as the second crop of a rice-wheat rotation where the fertilizer was applied prior to both crops. The same trends were observed with PAPR, however, regardless of the crop type, whether the response was measured following fresh application, or whether it was measured in the second crop following application. Also, in four out of five rotations where test fertilizers were applied only prior to the first crop and the second crop was grown without reapplication, significant residual response was observed and all sources (TSP, PAPR, and unacidulated phosphate rock) performed equally as well as the others. This occurred despite a general trend that showed unacidulated phosphate rock somewhat less effective in the initial cropping period.

On the basis of these positive results with PAPR, PPCL is presently in the process of designing a plant for commercial production of Mussoorie PAPR in India.

Agronomic Field Research—Africa

A key activity of the IFDC Africa Fertilizer Research Program was the organization of an international symposium in March at Lomé, Togo. In addition to reviewing the results of field trials conducted between 1982 and 1984, the symposium examined the constraints to fertilizer use, the policy issues that must be addressed by policymakers in order to remove the constraints, and several aspects of the fertility and productivity of tropical African soils.

With funding provided by IDRC, research activities of various collaborators in west Africa are helping IFDC to establish a fertilizer efficiency data base for sub-Saharan Africa. This data base will form a rational basis for setting up future research priorities by both IFDC and national research organizations within the region. The existence of the network (WAFFMEN) provides IFDC with a system for testing technological innovations over a range of ecological conditions. Such research has generated and sustained interest in the development of alternative P fertilizers using resources indigenous to west Africa. During 1985 testing of the agronomic effectiveness of Togo phosphate rock and the partially acidulated forms (PAPR) was continued in Cameroon, Nigeria, Togo, Sierra Leone, and Liberia. In Burkina Faso additional experiments were set up to evaluate Kodjari phosphate rock and PAPR. Tilemsi phosphate rock and PAPR were evaluated in trials with maize and groundnuts at two locations in Gambia. In Niger the agronomic effectiveness of Parc-W and Tahoua phosphate rocks and their partially acidulated forms was investigated in several on-station and on-farm trials.

The results of the 1985 trials confirm previous findings that P is one of the most limiting nutrients in the soils of tropical Africa. The widespread deficiency of P across all agroecological zones is a result of the very coarse parent materials from which the soils have formed. P sorption studies and field trials in both Niger and Burkina Faso showed that P application rates as low as 30 kg P_2O_5 per hectare could produce high and economic yields of millet. As in previous years, PAPR was, in many locations, as good as the superphosphates as a fertilizer containing both P and S. Measurements of the residual effectiveness of different P fertilizers at Sarakawa (Togo) and Gobery (Niger) showed that all sources had high residual effectiveness (Figure 12).

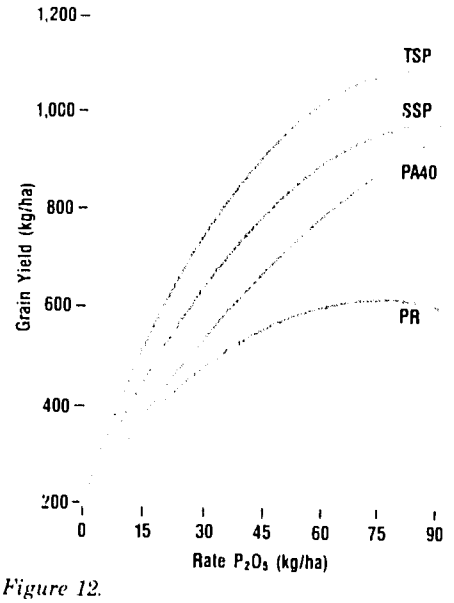


Figure 12.
Effect of Residual Phosphorus Sources and Rates on Millet Grain Yield (Gobery, 1985).

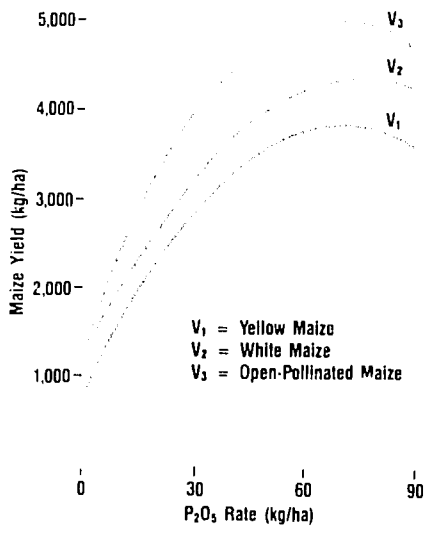


Figure 13.
Effect of Phosphorus Rate on Maize Yield at Guga, Nigeria (1985).

In Nigeria, experiments were set up in three locations in the savanna zone to assess the P needs of two hybrid varieties of maize. An open-pollinated variety was included as comparison. The result of the trial at Guga is presented in Figure 13. All maize varieties responded to P at all locations. In addition, the hybrids were found to be more efficient at using the native P in the soil. For the third year, results at Sadore (Niger) showed that the efficiency of fertilizers is dramatically improved when crop residues are incorporated in these very sandy, colloid-poor soils.

Special Research and Development Projects

Characterization of Phosphate Ores From Africa

Characterization studies were performed on three P samples from Benin; these samples representing the uncrushed and crushed ore contained about 28% P_2O_5.

This ore is composed primarily of phosphate pellets cemented by silica; minor amounts of aluminophosphate phases occur as fracture fillings. The rock is approximately 71% carbonate fluorapatite (francolite) with 23% silica, 2% aluminophosphates, and 1% limonite. The apatite has a relatively low carbonate substitution and therefore low reactivity. The nature of the gangue mineral (quartz) in the ore indicates that a number of flotation processes might be applicable for beneficiation. The beneficiated ore could be used in any number of fertilizer processes. Although the citrate solubility is rather low, this ore and its concentrate may be considered as a direct-application fertilizer on acid soils. It is also a good candidate for the partial acidulation process.

Studies of Colombian Phosphate Rock

At the request of a company in Neiva, Huila, Colombia, IFDC conducted an evaluation of a newly discovered deposit of phosphate rock, located in south central Colombia near the Andes Mountains.

During the past 20 years Colombia has focused much attention on the development of its indigenous deposits of phosphate rock, and IFDC has played an important role in assisting that country in evaluating its natural resources so that they can be used in the production of fertilizer to meet domestic needs.

During the 1960s Colombia, with help from the U.S. Geological Survey, conducted an extensive exploration program and found that it possessed rich deposits of phosphate rock, the most prominent of which are located at Sardinata and Pesca. These two deposits proved to possess great potential and have been studied by IFDC and other organizations for several years. Another phosphate deposit that was discovered later was the Huila deposit, located fairly close to the newest discovery.

The latest discovery is called the Media Luna deposit. A run-of-mine sample of this ore was received at IFDC in late 1984 and was chemically and mineralogically characterized to evaluate its potential as a fertilizer raw material. IFDC fertilizer technologists determined that the rock is a medium-grade ore composed of P, calcite, and quartz. The ore has good potential for direct application. It is a relatively pure rock with respect to all impurities except calcium carbonate. It is now an economic decision whether to remove this carbonate prior to fertilizer production or use it directly in the selected process.

Using sulfuric acid, IFDC technologists during 1985 produced PAPR with 50% of its P_2O_5 in the available form. After conducting experiments on the rock, they found that it is feasible to produce PAPR using IFDC's single-step acidulation and granulation process.

Studies of Australian Phosphate Rock

A project being sponsored by a company in Australia is studying the processing characteristics of phosphate rock from the Duchess deposit. Because the rock has a high silica content, the experience gained from this research will help IFDC deal with similar problem ores from developing countries.

The deposit contains 1,400 million tons of phosphate rock and is located in the Georgina Basin in the northeastern Australian state of Queensland. Following the discovery of the deposit in 1966, a mine was developed and operated for several years during the 1970s. Some of the phosphate rock was used domestically, and some was shipped to Taiwan, the Philippines, Korea, and Japan. In the late 1970s the mine was closed for economic reasons.

The company is now considering a plan to build a phosphoric acid plant that would use byproduct sulfuric acid from a nearby copper smelter. The concentrated phosphoric acid will be transported to the fertilizer plant and converted to granular TSP by reacting it with additional rock or to ammonium phosphates by reacting it with ammonia. These products would then be available for shipping to Australian ports and to Asia.

Pilot-plant tests on the performance of the rock in the production of phosphoric acid have been performed in Japan, England, and the United States. Part of the phosphoric acid from the tests was sent to IFDC for additional testing and conversion into granular TSP, MAP, and DAP. These tests were begun in late 1985 in the continuous laboratory-scale granulation unit. The products prepared in this unit are undergoing physical properties testing.

Sulfur Research

In the past the sulfur requirements of crops have usually been satisfied by the incidental application of S in low-analysis N and P fertilizers such as ammonium sulfate and single superphosphate. However, increased usage

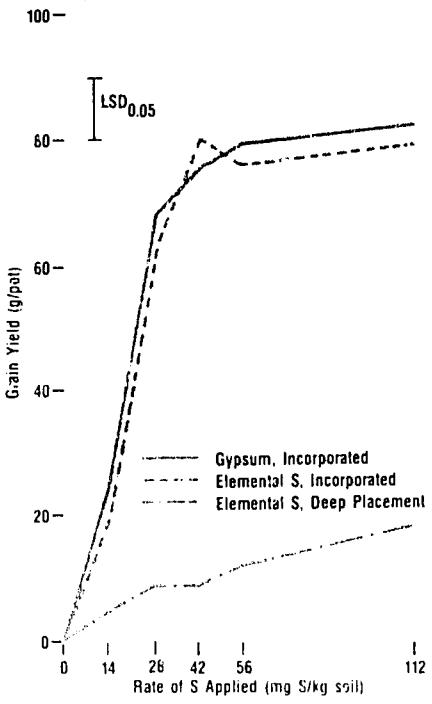


Figure 14a.
Rice Grain Yield (first crop) Obtained With Gypsum and Elemental S as Influenced by Placement Method of S Fertilizers.

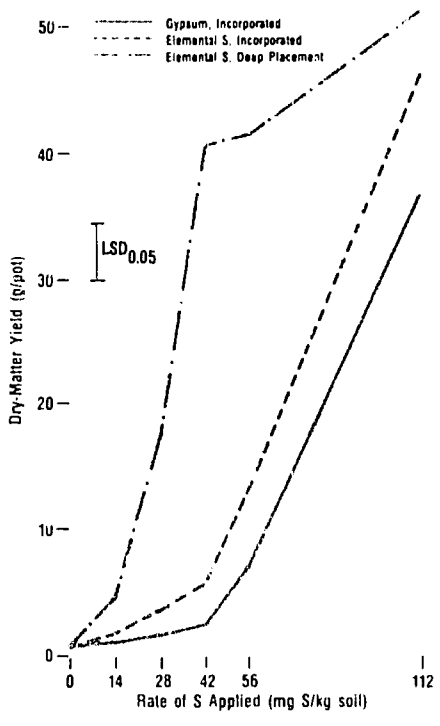


Figure 14b.
Dry-Matter Yield of Rice (second crop) Obtained With Gypsum and Elemental S as Influenced by Placement Method of S Fertilizers Prior to First Cropping.

of high-analysis S-free products, such as urea, TSP, and DAP, and increased demands placed on soil S reserves by intensified cropping with high-yielding varieties have led to an increased incidence of S deficiency in the tropics. The objectives of IFDC's Sulfur Program include the evaluation and manipulation of S-containing fertilizers to correct these deficiencies and the explanation of S transformations and loss mechanisms in the soil that affect the availability and efficiency of S-containing fertilizers.

Greenhouse Research

As part of the evaluation of "urea-sulfur melt" as a combined source of N and S for flooded rice, an experiment was conducted to investigate the initial and residual value of deep-placed elemental S to subsequent crops of rice or rice/maize rotation. In general agreement with earlier results, it was found that elemental S and gypsum incorporated with urea were equally effective in increasing rice grain yields while elemental S deep placed with urea was ineffective (Figure 14a). It is presumed that deep-placed S initially oxidizes very slowly and is unavailable to the first crop.

Although deep-placed elemental S was ineffective for the first rice crop, it became very effective for the second rice or maize crop (Figure 14b). For rice, the necessary soil preparation, which involved partial drying (aeration) and mixing (plowing) prior to reflooding, was adequate to oxidize deep-placed elemental S and increase its availability. Incorporated elemental S and gypsum treatments, in contrast, showed very poor residual value for the second rice crop. This was probably due to substantial removal of fertilizer S in the first crop, particularly at the lower application rates.

Sulfur needs for maize were less than for rice, thus the maximum growth of maize was attained at lower S application rates with all sources. Probably greater mineralization and plant uptake of S from soil organic matter were possible under upland conditions during the cropping period. This is supported by results of a separate experiment on a different soil using radioactive ^{35}S-labeled elemental S and gypsum in which rice plants derived twice as much of their S from the soil when grown under upland conditions than when grown under flooded conditions.

Deep placement of urea has been shown to be a very efficient means of applying N to flooded rice. The results of this study demonstrate that, although deep point-placed urea-S is an ineffective S source for the rice crop to which it is applied, elemental S is very effective for succeeding crops grown under either upland (maize) or flooded (rice) conditions. This finding is particularly important in the continuous rice-cropping system provided that the deep-placed urea-S is supplemented with a sulfatic source (e.g., ammonium sulfate or gypsum) in the first season.

Leaching of sulfate is the major loss mechanism of fertilizer S from soil. Leaching losses can be reduced by applying S in elemental form, but plant uptake may also be affected. In 1985 a greenhouse experiment with ^{35}S-labeled sources was conducted to com-

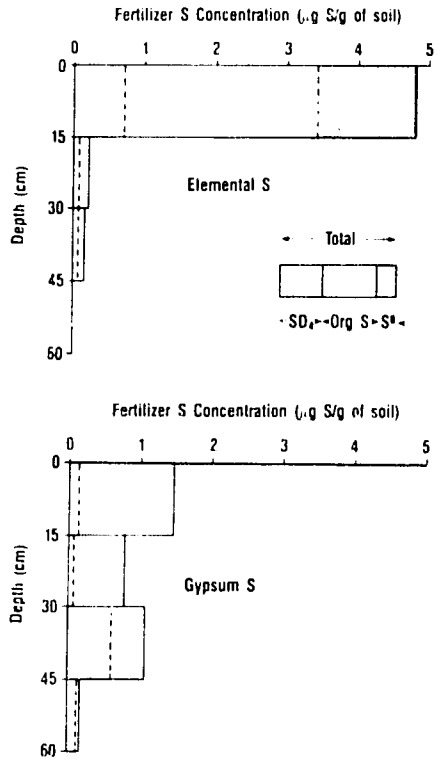


Figure 15.
Fate of Surface-Applied Elemental S and Gypsum in Soil Profile After Cropping With Maize in Deep Containers.

pare the gypsum and elemental S. Maize was grown to maturity in reconstructed 70-cm deep soil profiles in tall containers. At harvest 57% and 39% of S from elemental S and gypsum fertilizer, respectively, was recovered in the soil profiles. Approximately 53% of the applied elemental S (16% of which remained unoxidized) was found in the top 0- to 15-cm layer of soil; whereas, residual gypsum was distributed relatively uniformly to a depth of 45 cm (Figure 15). However, recovery of elemental S in maize top growth was only one-half that of gypsum (15% versus 29% of S applied, respectively). This is attributed to a lower rate of S uptake from the elemental S source during the early stages of growth when oxidation to sulfate was low. These data indicate that, while leaching of fertilizer S through the soil profile can be reduced by using insoluble elemental S sources, crop uptake may also be reduced possibly necessitating an adjustment of fertilizer rates for optimal growth.

Field Research

In 1985 the sulfur program and its collaborators established field experiments at sites in west Africa where S deficiencies had previously been observed in P source trials comparing

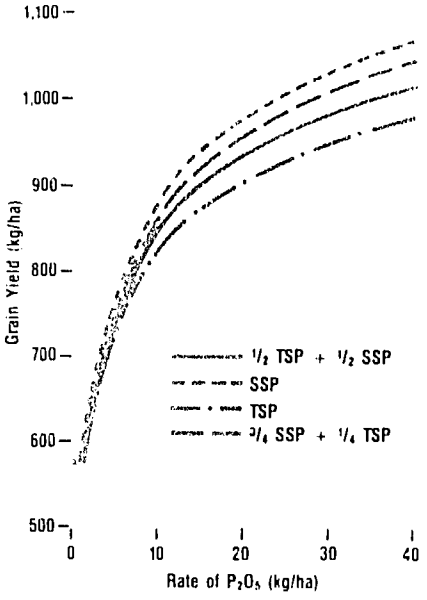


Figure 16.
Phosphorus/Sulfur Requirements for Millet, Sadore, Niger, 84/85.

Workers in Niger incorporate fertilizer in a sulfur experiment.

SSP and S-free TSP. These experiments compared phosphogypsum and elemental S (minus 60-mesh) for maize in the subhumid agroecological zone (Togo) and millet in the semiarid zone (Niger). Maize responded equally well to phosphogypsum and elemental S at the subhumid site, yielding 55% more grain with S fertilizer than without. No millet responses were observed in the semiarid zone trials in Niger. The millet in these latter trials was planted on newly cultivated land that apparently contained an adequate though low reserve of mineralizable S. The results conform to IFDC's earlier experience at the same sites where apparent S deficiency was observed after a period of 2-3 years of cropping without S-containing fertilizers.

At one site in Niger, ^{35}S-labeled materials were used to monitor the fate of fertilizer S in the crop and soil profile. Of the 20 kg S/ha applied as phosphogypsum, 2 kg S/ha was recovered in the top growth of the millet. An additional 4 kg S/ha was taken up from the native S pool. Approximately 75% of the applied gypsum was recovered in the soil and was distributed in a broad band centered at 45-cm depth, showing considerable penetration into the profile. Most remained in the sulfate form with little immobilization into organic matter and would thus be susceptible to further leaching with the onset of the next rainy season. Only 8% of the elemental S fertilizer was recovered in the soil at harvest (crop uptake was approximately 1 kg S/ha). The fate of the remaining (≅90%) elemental S is unknown. Future work will be done to evaluate elemental S applied in granulated sources such as the urea-S melt and S-fortified TSP and PAPR.

While the nutritional importance of S in SSP has been demonstrated in IFDC's field experimentation in west Africa, the S content of this material is probably greater than required (typical P:S ratio = 0.7-0.8); this results in an excessive dilution of the fertilizer's P content. During 1984 and 1985, experiments were conducted in Niger using mixtures of SSP and TSP to determine the most appropriate P:S ratio of superphosphate fertilizer. Because the proportion of SSP in the mixture was reduced, yield response to applied P also declined (Figure 16). Of the mixtures tested, only TSP yielded significantly less than SSP. The reduced yields could not be explained by the minor differences in the P solubility of the TSP and SSP and were therefore

attributed to declining S content in the mixtures. The results indicate that the S content of superphosphate could be reduced by at least 50% (and possibly more) without significant loss of yield. The resultant higher analysis material could substantially reduce shipping and handling costs, an important consideration given the distances fertilizer must be transported in Africa.

Economics Research

It is generally accepted that the successful development of improved fertilizer technologies and their adoption by the developing countries depend upon the economic return that these technologies can generate. This is especially true for the countries of Africa; however, many of these countries are beginning to realize the beneficial role that fertilizer can play in increasing food production in their countries. In the words of IFDC's Managing Director Dr. Donald L. McCune, "The situation in Africa is changing; 5-6 years ago, the ministries of agriculture felt that they could not afford to use fertilizer. Now they feel that they cannot afford to not use fertilizer. The attitudes in Africa are changing toward fertilizer."

IFDC's economics research program carries out economic analyses and enlarges the information base upon which various research and development policies concerning fertilizer technology development and transfer are formulated. This information is not only vital to the work of IFDC's fertilizer technologists, soil scientists, and engineers, but also it is important to the decisionmakers in developing countries.

During 1985 the economics research program made progress in several areas. The Fertilizer Evaluation Program and Information System was fully developed and implemented. Fertilizer policy research projects were conducted in sub-Saharan Africa and Southeast Asia. Farm-level socioeconomic research was carried out in India and Colombia. Various reports providing market-related statistics were compiled.

Fertilizer Evaluation Program and Information System

During 1985 significant progress was made in the establishment of the Fertilizer Evaluation Program and Information System. A data base is now established containing data from most of the fertilizer field experiments that IFDC has conducted around the world in collaboration with national and international organizations. Also, progress was made in: (1) establishment of a fertilizer efficiency information system, (2) development and use of better methodologies to evaluate the agronomic and economic performance of fertilizer products and practices, and (3) refinement and expansion of capabilities of crop-modeling techniques to evaluate fertilizer and crop production technologies and extrapolate results.

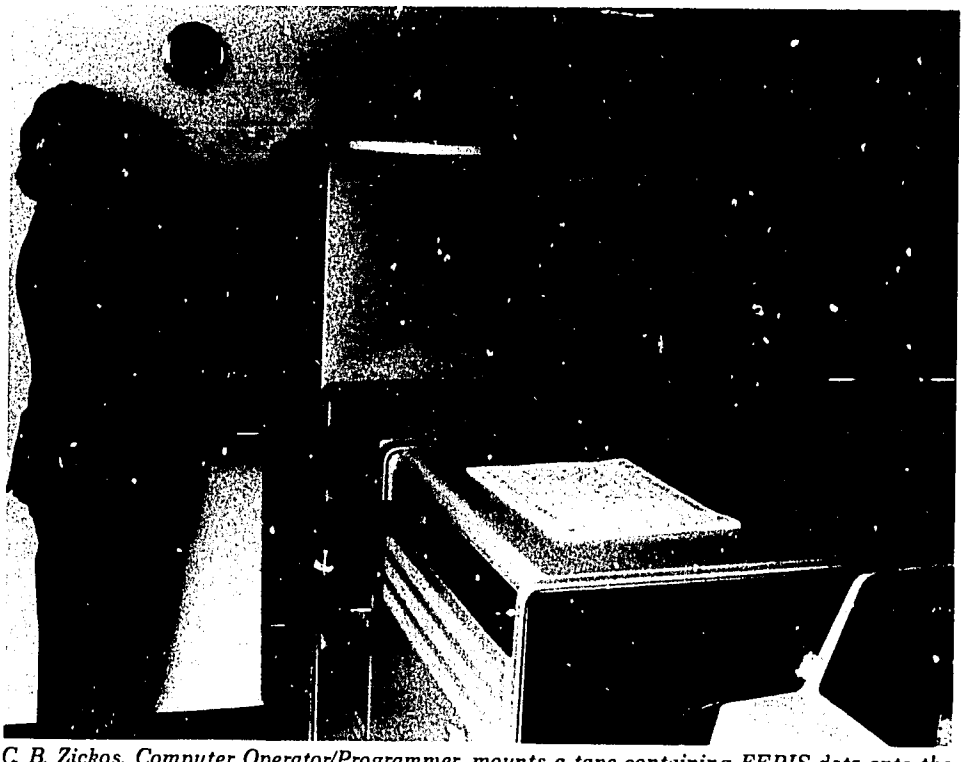
Fertilizer Data Base

Data from fertilizer field experiments on N, P, and S have been incorporated into the data base. The data base consists of an integrated set of records related by specific site and agroclimatic variables. The data base is organized according to a relational system, which facilitates data analysis and reporting. This system allows for flexibility to update and expand the data base to incorporate other types of data such as socioeconomic variables and data from greenhouse experiments. Data can be easily accessed for analysis or to obtain descriptive summaries in the form of tables.

Table 7 contains a summary of the type of data, countries, and crops included at present in the data base.

Crop Modeling

During 1985 refinements to the upland nitrogen balance components of the Crop Evaluation Through Resource and Environment Synthesis (CERES) models were made to improve simulation of denitrification and remobilization of nitrogen within the plant during grain filling. An extensive sensitivity analysis was made to deter-



C. B. Zickos, Computer Operator/Programmer, mounts a tape containing FEPIS data onto the Center's computer.

mine which were the most critical elements of the model. The analysis highlighted the importance of quality weather data and soils information to enable accurate prediction of fertilizer performance and crop yield.

In collaboration with the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project (University of Hawaii) and Michigan State University, IFDC developed a first approximation upland rice-nitrogen model. Work is now underway to develop the model further to accommodate the permanently and periodically inundated soils usually associated with rice production.

Techniques to facilitate the evaluation of fertilizer strategies under uncertainty were further developed. Using the CERES-maize-nitrogen model coupled with a weather simulator, the growth of maize crops was simulated on a daily basis for each of 20 years for two locations in west Africa. In one location (Kandi, Benin) droughts are frequent, and significant response to fertilizer is obtained only 1 year in 5. Complete crop failure occurs 1 year in 5. At the other location (Cotonou, Benin) responses occur in all years. Analyses of the simulations indicate large differences in fertilizer recovery and efficiency between the two locations. When economic factors are added to the analysis, the model becomes a powerful tool for evaluation of differing fertilizer use strategies.

Table 7. Summary of Data Base Information.

Countries	Type of Data: Site Factors	Crop Management	Fertilizer	Crops
Colombia	Soil classification	Planting date	Product	Rice
Mali	Soil depth	Harvest date	Application:	Maize
Nigeria	Soil analysis	Plant density	-Method	Millet
Senegal	Soil moisture	Crop variety	-Time	Sorghum
Togo	Slope	Pest control	-Rates	Groundnuts
Liberia	Rainfall	Irrigation use	Initial and residual effects	Cowpeas
Cameroon	Temperature maximum/minimum			Beans
Sierra Leone	Relative humidity			Maize/cowpeas
Burkina Faso	Agroclimatic region			Maize/beans
Gambia				Maize/sorghum
Niger				Cassava
Kenya				Potatoes
India				
Bangladesh				

Table 8. Status of Information System.

Type of Information	Fertilizers	Countries
Fertilizer response functions	Urea	Colombia
Indexes of agronomic efficiency	USG	Nigeria
Indexes of economic performance	CAN	Niger
Agroclimatic regions	Ground phosphate rock and partially acidulated phosphate rock—from ores at Huila and Pesca (Colombia), Togo (Togo), Tilemsi (Mali), Kodjari (Burkina Faso), and Parc-W (Niger)	Togo
Crops and cropping systems	TSP	Sierra Leone
Soil characteristics	SSP	Burkina Faso
Location of field experiments		Kenya
		Gambia

Information System

The development of a relational information system was begun in 1985. Files containing information about fertilizer response estimates, soil and crop management variables, and results of economic analysis are incorporated into this system. The information system is being developed as a component of the overall relational data base/information system so that information can be easily related to basic data and vice versa. The information system is continuously updated as results are obtained through the statistical and economic analysis of new data. Table 8 contains a summary of the present state of the information system in terms of countries, fertilizer products, and type of information that is included.

Computer application programs were developed to access the system and retrieve information in an interactive and selective way. Information may be obtained for a given agroclimatic region, country, crop, cropping system, type of soil, and fertilizer product. Also, because crop and fertilizer prices do not remain constant, application programs were developed to access the system and interactively input new prices and update results of economic analysis. Information in the system may be retrieved and obtained in the form of tables and graphs (fertilizer response, economic returns).

Fertilizer Policy Research

Fertilizer policy research at IFDC is designed to provide an overview of fertilizer policies in different countries and regions, evaluate the economic implications of public policies, analyze the economic consequences of fertilizer technology, and generate information appropriate for formulating public policies. During 1985 IFDC's policy research was focused on (1) fertilizer policy in sub-Saharan Africa, (2) fertilizer policy in Southeast Asia, and (3) energy and fertilizer policy—an update.

Fertilizer Policy in Sub-Saharan Africa

This study deals with an overview of fertilizer problems and policies in sub-Saharan Africa, which consists of over 40 low-income tropical countries. Recently, world attention has been focused on many of these countries to assist them in formulating and implementing short-term and long-term strategies to reduce serious food and nutrition problems and to develop food production potential.

Fertilizer use, along with other complementary inputs, has played a great role and will play an even greater role in accelerating agricultural growth. However, the present level of and growth in fertilizer use are extremely low. In many cases fertilizer growth was found to be negative. The average fertilizer use in sub-Saharan Africa is 6.9 kg/ha, which is 14% of the average in developing countries. The aggregate fertilizer consumption is about 1 million tons of nutrients, which is 30% of the consumption in continental Africa.

The study concludes that, in addition to creating the necessary institutions and infrastructure to serve agriculture, there is a need for major policy reforms in at least four areas in order to expand fertilizer demand. These reforms would need to (1) raise fertilizer efficiency, productivity, and response through the development of appropriate fertilizer technology and management (Government policies must encourage the development and use of indigenous phosphate resources.); (2) improve incentives, increase profitability, and reduce risk from fertilizer use through appropriate price, subsidy, and credit policies; (3) transfer and disseminate fertilizer technology and management practices through appropriate fertilizer recommendations and promotion policy; (4) improve crop response to applied fertilizer through the development and transfer of fertilizer-responsive crop varieties expansion in irrigation, and investment in agricultural research; and (5) remove serious fertilizer marketing and supply constraints in order to expand fertilizer demand and economic use of fertilizer.

Fertilizer Policy in Southeast Asia

A collaborative project on rice policies in Southeast Asia was initiated by three international agricultural research institutes: International Food Policy Research Institute (IFPRI), IFDC, and IRRI. The purpose of the project is to understand and analyze the impact of government policies on rice production, consumption, and trade in four Southeast Asian countries.

Fertilizer is one of the vital inputs into rice production and hence influences the levels and stability of rice production and prices. Fertilizer policy is one of five subprojects of the collaborative IFPRI/IFDC/IRRI rice policy project.

The fertilizer policy project has been initiated in collaboration with researchers from (1) Ministry of Agriculture and Gajah Mada University in Indonesia, (2) Universiti Pertanian Malaysia, (3) Bureau of Agricultural Economics in the Ministry of Agriculture in the Philippines, and (4) Kasetsart and Chulalongkorn Universities in Thailand. Six working papers have been drafted and are at different stages of completion.

Energy and Fertilizer Policy: An Update

A previous energy study has been updated to incorporate more recent survey data. The results indicate that even though energy consumption requirements have declined the potential for improving energy efficiency in the fertilizer sector is still large. Nitrogen fertilizers account for a major share of energy use in the fertilizer sector. Energy costs account for the largest share in total ammonia production costs. In 1973 this cost averaged $33.60/ton of ammonia in the United States; in 1982 it had risen to $137.54. Despite softening of the world energy market and decline in crude oil prices, there is no reason for complacency, especially for energy-deficit developing countries. There is a need to continue and even increase efforts to improve energy efficiency at all levels, including fertilizer production, marketing, and use.

Farm-Level Socioeconomic Research

IFDC's farm-level socioeconomic research provides the necessary insight into problems encountered by small farmers in adopting fertilizers or fertilizer-related technology. The objectives of this research are to identify problems either common to farmers worldwide or typical for specific agroecological and socioeconomic settings, and help develop means to overcome such problems. In addition, the research provides essential farm-level information to help narrow the focus and increase the effectiveness of the N and P agronomic research programs.

India

In 1985 research was initiated in collaboration with ICRISAT for the semi-arid tropical region of India to determine how variations in soil quality affect farmer fertilizer management practices and the economc returns to chemical nitrogen fertilizer on dryland food grains. A rapid diagnostic survey, consisting of initial, narrowly focused interviews with a few farmers, followed by a formal questionnaire administered to a sample of farmers, was carried out in three Indian agroclimatic regions to identify farmers' classification of soil types, use of farmyard manures, and experiences with chemical fertilizers. Patterns of soil-crop-fertilizer use among farmers were identified. For example, in one Indian village, the research found that unreliable kharif season rains and sandy soils with low moisture-holding capacity constrained farmers' fertilizer use on sorghum. In a different agroclimatic zone, where farmers grow sorghum on deep black soils, the research identified the potential for increasing production and farm income through increased use of fertilizer. Fertilizer trials were established in farmers' fields to test this hypothesis. The interviews and experimental

data were combined to estimate fertilizer response as a function of soil type. Farmer assessment of soil quality was compared with other methodological tests, and preliminary results showed that mineralizable-N testing appeared preferable to other methods.

Colombia

The rapid key-informant survey is designed to provide a description of farmers' practices without the quantification provided by a survey, but with the addition of qualitative detail about socioeconomic features of the whole farming system that help to identify ways in which experimental fertilizer testing can be linked to farmers' overall strategies for increasing farm income and welfare. The information is obtained and written up in approximately 6 weeks by an experienced social scientist who lives at the research site. Two such studies conducted for the phosphorus program's field testing sites in Colombia, South America, revealed that

1. There is a growing demand among small farmers for organic/inorganic fertilizer mixtures;
2. Farmers in both areas give fertilizer residual effects a heavy role in determining fertilizer types, crop rotations, and fertilizer mixtures;
3. Among small farmers in Colombia, fertilizers are often considered to be a last resort for degraded soils rather than a general means to enhance crop productivity;
4. The typical path for new fertilizer diffusion among small farmers is to experiment on less risky crops and only then apply new fertilizers to their main cash crop.
5. Other farmers have determined appropriate fertilizer dosages; they fertilize their highest value crops first and only then apply fertilizer to other crops, often those destined mainly for household consumption.
6. Tenure type is a key variable in explaining fertilizer use choices because of the farmer's awareness of the long-term effects of fertilizers in improving soil fertility. Private tenure or long-term rental arrangements are most conducive to fertilization; farmers with annual leases or plans to move off the farm are unwilling to plant fertilizer-demanding crops or to apply proper dosages of fertilizer.

The introduction of new phosphate rock-based fertilizer technology into small-farm systems in Latin America will require farmers to have an understanding of the nutrient balance of different fertilizers in order for them to use the new single-nutrient phosphorus products correctly. Constraint studies in two field sites in Colombia developed a fertilizer knowledge test to investigate farmers' understanding of fertilizers that they are currently applying. The results showed a serious deficiency in farmers' knowledge of some basic concepts pertinent to correct fertilizer use: on an index of ten items that discriminated among farmers only 4.5% of the farmers scored ten correct responses. For example, in Nariño where farmers apply high dosages of compound fertilizers to the potato crop, about 30% of the farmers could name either N, P, or K as important for plant growth; over 50% were aware that their soils were deficient in P; but over 30% could not relate these terms to the formula on a fertilizer bag. Most farmers did not know what an "acid" soil implied—a critical factor when the effectiveness of direct application of phosphate rock depends on acid soils.

The same study found, however, no significant relationship between farmers' scores on the fertilizer knowledge index and compound fertilizer dosages applied or productivity. This finding illustrates the fact that when the farmers lack technical knowledge about fertilizer, they conduct their own trial-and-error testing to determine the correct dosages for their crops. Participatory research in its diagnostic phase has focused therefore on studies of farmers' experimentation with fertilizers as part of a methodology to elicit farmers' concepts of how they themselves would test phosphate rock technology. Farmers' ideas are then integrated into on-farm testing by means of the farmer design trials. Farmer experiments provide a rapid diagnostic tool for pinpointing the production constraints perceived by farmers and show how they attempt to resolve them. These experiments also show the cutting edge of local innovation and hence likely adoption. They can also show how farmers attempt to adapt technology to their particular circumstances. The diverse constraints, necessities, and problems of small farmers when dealing with fertilizer technology are encapsulated in some of these experiments, and they offer guidelines for refining small farmer-oriented research.

Farm-Level Fertilizer and Crop Prices

During 1985 IFDC continued to collect and analyze mid-month farm-level prices for principal fertilizer products and crops in 45 countries primarily in Africa, Asia, and Latin America. Data collection from in-country collaborators was begun in late 1979. Prices are obtained in local currency and are converted to U.S. dollars per metric ton as a standard unit. This information is maintained on the computer and is available for determining fertilizer and crop price relationships as needed in various research projects. For reference, an updated price summary by country, month, and year for each fertilizer product or crop is prepared and distributed each month within IFDC and to interested organizations such as international agricultural research institutions, international development assistance organizations, and fertilizer companies. Farm-level prices, which can be analyzed to determine changing trends in farmers' incentives to use fertilizer, are of value to policymakers in developing countries. This information is also helpful in analyzing various policy proposals to determine why farmers in some countries apply fertilizer at a much higher rate than those in other countries.

Fertilizer Price Survey

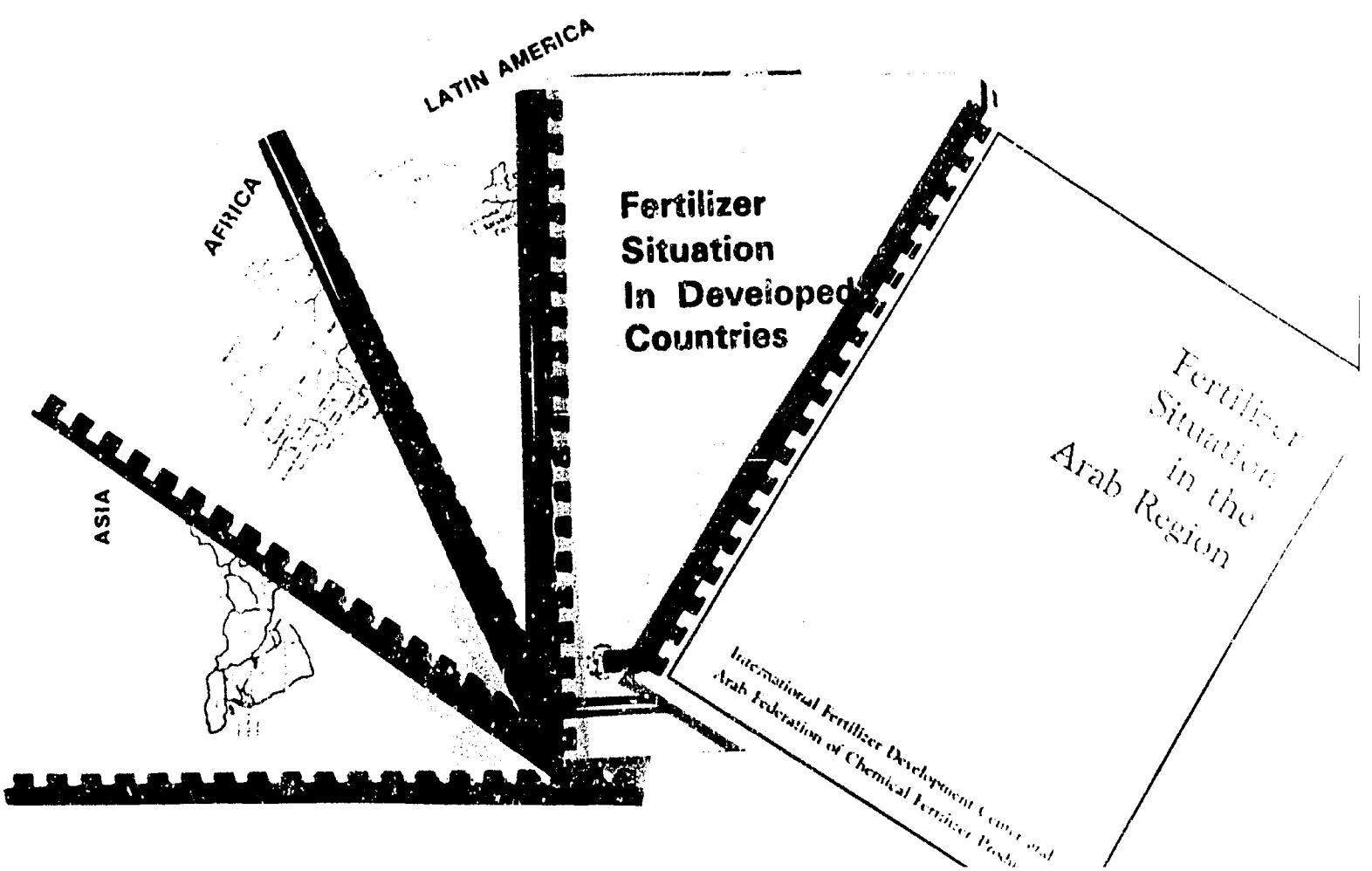
IFDC began conducting a semiannual survey on expected changes in world fertilizer market prices with about 50 major fertilizer company executives around the world. The survey, conducted on January 1 and July 1 each year, obtains from respondents their estimated percentage changes in world market prices of urea, ammonium sulfate, DAP, TSP, muriate of potash, and sulfur during the following 6 months. This information has been used in IFDC training programs and is provided as a service to the fertilizer industry.

Regional Fertilizer Supply/Demand Statistics

IFDC continued to compile updated national fertilizer supply and demand statistics every 6 months on a product basis. Statistics are collected from correspondents in developing and developed countries. At present, product statistics are available for 79 developing countries and 28 developed countries. A considerable amount of statistical information is already available on a nutrient basis but not on a product basis. Subject product statistics were incorporated in IFDC's four regional fertilizer situation reports prepared in 1985. These reports are "Asia Fertilizer Situation," "Africa Fertilizer Situation," "Latin America Fertilizer Situation," and "Fertilizer Situation in Developed Countries." Included also in the reports are the world and regional production, consumption, exports, and imports for fertilizer N, P, and K, and production capacities for selected fertilizer materials. All situation reports are updated approximately every 6 months.

Fertilizer Supply/Demand Situation in the Arab Region

IFDC and the Arab Federation of Chemical Fertilizer Producers (AFCFP) jointly prepared a publication entitled *Fertilizer Situation in the Arab Region in 1985*. Relevant data for 1979-83 and for 1984 (where available) were gathered by AFCFP. The report contains pertinent information on fertilizer raw materials (natural gas, phosphate rock, potash, and sulfur), on intermediates (ammonia, phosphoric acid, sulfuric acid, and nitric acid), and on finished fertilizers. Production, consumption, exports, and imports for finished fertilizers were given on a product basis as well as on a nutrient basis.



National Programs

What is the situation of developing-country agriculture from the national decisionmaker's perspective? According to IFDC's Deputy Managing Director, Dr. Paul J. Stangel, decisionmakers in developing countries are eager to look at ways of directly applying the research results that have been accumulated during the past 10 years. As for Africa, there is an awareness at the national level that greater use of fertilizer, when placed in an overall agricultural framework, is an absolute must if African countries are to reverse the last two decades of declining food production. National leaders in Africa are very eager to gain the latest scientific information to solve the problems of their countries.

Moving next to Asia, we find an entirely different situation. Increased supplies of basic food commodities are beginning to accrue in countries like China, India, and Indonesia. This situation has caused national leaders to look for ways to diversify their agriculture. As a result of increased incomes, the diets of the people are improving. There is a greater demand for a wider variety of foods. There is an increasing demand for information on vegetables and proteins, as they assume greater importance. Research results that have been obtained by IFDC as well as other international agricultural research centers are being sought after and incorporated into new agricultural policy designs to meet the continent's changing needs.

As a result of these changes, IFDC feels that national programs take on even greater importance in serving the people of the developing world. Research results accrued from our work in Bangladesh, Indonesia, and Mali are now being rapidly incorporated by policymakers in their agricultural strategies. According to Stangel, the kind of national program that IFDC has established in Mali needs to be extended to other countries of Africa to effectively tackle the food crisis that is gripping much of that continent.

Bangladesh

1985 marked the seventh consecutive year of IFDC's involvement in providing fertilizer marketing and distribution consultancy services to the Bangladesh Agricultural Development Corporation (BADC), the government-sponsored agricultural inputs marketing organization. This technical assistance to BADC is funded under the Fertilizer Distribution Improvement Project of the USAID, whose main goal is to raise crop production by removing those constraints to fertilizer supply and use that limit the expanded and more effective use of fertilizer. Under this project, IFDC assists BADC in implementing and strengthening its private sector-oriented New Marketing System (NMS), which was introduced to improve the cost-effectiveness of the marketing function while making it more responsive to farmer needs. The NMS, under BADC's management and with input from IFDC, has increased the availability of fertilizer to farmers and controlled marketing costs despite increasing inflation. During the period of the Center's participation in this project, fertilizer use in Bangladesh increased from 754 thousand tons in 1978/79 to 1.26 million product tons in 1984/85, an increase of 67%. The production of rice, the predominant food grain, trended upward despite frequent weather-related calamities; it has risen from 12.7 million tons in 1978/79 to 14.3 million tons in 1983/84. Wheat production more than doubled during that period.

Recognizing the need to consolidate gains and build on past achievements, in mid-1985 BADC extended its consultancy agreement with IFDC for another year. However, with the winding down of the USAID Fertilizer Distribution Project and decreased availability of project funds, the IFDC/Dhaka-based consultant team was reduced from three to one resident consultant.

As in past years, IFDC's resident consultants worked side-by-side with BADC counterparts to prevent or overcome day-to-day problems associated with the planning, management, and monitoring of the NMS. The participatory and pragmatic nature of the resident consultant programs strengthened and expanded the skills of BADC marketing personnel and promoted the transfer of improved technologies. Providing additional program support, IFDC staff members served as short-term consultants on specialized problems. Special project activities conducted in 1985 continued to emphasize human resource development and included in-country and overseas training programs and fertilizer use efficiency research.

Given the high level of accomplishment of its Fertilizer Distribution Improvement Project, USAID and BADC jointly planned a second phase of this project to focus on expanding the role of private-sector wholesalers and retailers in the NMS.

Fertilizer Distribution

In 1985 fertilizer distribution-related activities were centered on consolidating and refining the earlier developed stock control, accounting, and warehouse management programs. Fertilizer transport planning, routing, and contracting activities were continued to keep pace with changing transport needs and costs. On-the-job training was a continuing process in respect to each of the activities.

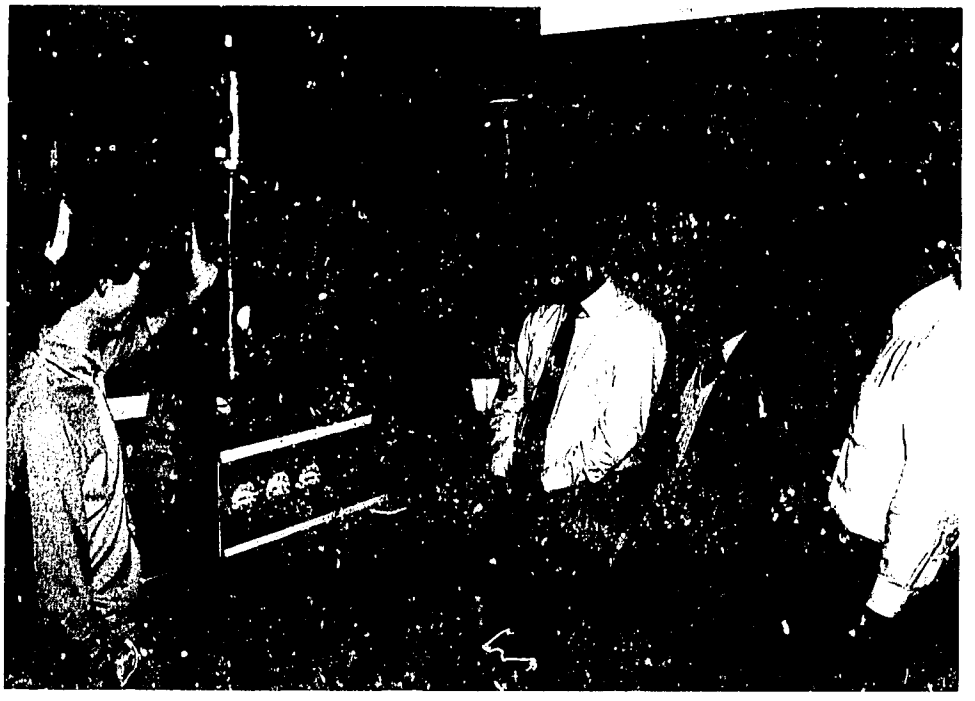
Stock control and accounting activities included development and implementation of methods for the simultaneous determination of stock in transit and that in warehouses to more accurately ascertain total stocks and stock losses. Personnel were trained in each of these procedures. Annual fertilizer transport and storage requirement plans, by sales warehouse, were developed for the current year and each year of the government's third 5-year plan. Assistance was provided in preparing fertilizer supply/demand projections and import requirements for 1984/85 and 1985/86. The comparative economics of importing various phosphate fertilizers was studied, and recommendations were submitted regarding procedures for importing fertilizers in bulk form and bagging in locally available jute bags to reduce overall fertilizer cost.

Fertilizer transport-related activities included updating the least-cost fertilizer transport plan, taking into account increasing freight costs, and preparing new truck and boat transport contracts and schedules for 1985/86 and 1986/87.

In 1985 a warehouse inspection program was inaugurated to ensure proper warehouse maintenance management.

Fertilizer Marketing

In 1985 IFDC placed greater emphasis on assisting BADC in improving the organizational structure and the planning and management functions of the marketing system. The consultants prepared a comprehensive marketing plan for 1985/86 that incorporated plans for fertilizer procurement, sales, movement, manpower development, crisis management, dealer development and training, and market research. Improved planning and monitoring will help prevent the recurrence of spot shortages of fertilizer, which arose late in the 1984/85 fertilizer season.



Bangladesh officials visited IFDC Headquarters during 1985. Here, Bobby W. Biggers (left), IFDC Chemist, discusses the laboratory-scale fluidized-bed coating equipment with K. Z. Rahman, Fertilizer Project Assistant, USAID/Dhaka; A.T.M. Ahsanullah, Member Director—Supply, BADC; and Dr. E. C. Kapusta, IFDC Regional Coordinator—Asia.

The consultants continued their monthly surveys of farmers and fertilizer dealers to determine fertilizer availability; farm fertilizer and crop prices; source, usage, and cost of farmer credit; fertilizer use rates; and information sources. This information provides a useful gauge of the performance of the fertilizer marketing system.

In 1985 several new activities were undertaken to improve the operation of the marketing system. To promote the development of larger scale fertilizer wholesalers, a quantity discount program was devised and implemented at key sales points, and a monitoring system was initiated. Studies were made and action taken to reduce distribution costs by closing redundant, smaller sales warehouses and consolidating sales at larger warehousing points. Field studies were made to identify necessary improvements in infrastructure (roads, bridges, storage, handling, and load-out equipment) to facilitate access to and handling and transport of fertilizer by dealers and farmers.

Field trips were made regularly to observe and identify problems in sales warehouse operations and to fertilizer retailers and wholesalers to monitor the performance of the marketing system from their perspectives. Special 1985 reports dealt with supply/demand forecasts, inventory status and control, bagging of byproduct gypsum, and the potential agronomic need for zinc and sulfur.

Dealer Development and Training

An independently conducted review of BADC's dealer development and training program affirmed the need for and successful implementation of the program that has to date assisted some 20,000 fertilizer dealers in improving their fertilizer promotional capabilities and farmer service programs. In 1985 the dealer development and training program continued to strengthen dealer knowledge in the agronomic and

economic aspects of fertilizer use so that they could provide more and better information to farmers. In 1985, 284 dealer training programs were conducted; over 3,500 dealers participated.

Three week-long fertilizer dealer trainer training programs were conducted to prepare 45 BADC marketing staff members for the task of conducting regional dealer training programs. IFDC assisted BADC in preparing curricula, lesson plans, lectures, and training aids used in the train-the-trainer and dealer training programs that were conducted on a national basis during 1985.

IFDC assisted in reviewing and adapting the latest fertilizer recommendations by the Bangladesh Agricultural Research Council (BARC) for use in fertilizer dealer training programs and promotional materials. The consultants assisted the dealers in establishing fertilizer test plots to demonstrate the benefits of fertilizer use to farmers. Additional fertilizer promotion and sales aids were prepared and distributed to dealers.

In 1985 numerous visits were made to fertilizer dealers' shops to monitor shop management, sales and promotional practices, and farmer service programs.

Special Projects

Agronomic Services

Evaluation of deep placement of urea for rice was the principal component of this project. The research was coordinated by BARC with assistance from IFDC. It was conducted by the Bangladesh Agricultural Research Institute and Bangladesh Institute for Nuclear Agriculture. The objective of the research was to assess the potential of deep placement of urea for increasing N use efficiency by rice in various agroclimatic zones of Bangladesh.

Split broadcast and single applications of deep-placed urea were compared in N response field experiments during six crop seasons (three dry and three wet seasons). The maximum rate of N ranged from 155 to 217 kg/ha. Twenty-one experiments were conducted at 11 locations during dry seasons and 19 experiments at 10 locations during wet seasons. Yield responses to deep-placed urea were rather consistently superior to split broadcast during dry seasons, but inconclusive results came from wet-season experiments. Project results from dry-season experiments for locations where more than 1 year's data were obtained are reported. Additionally, data from International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) experiments conducted by the Bangladesh Rice Research Institute at Comilla are included (3 years).

Yield response data were analyzed by regression analyses, first on individual experiments and then on pooled data over years at each of eight locations. Estimated average yield increases from applications of 120 kg N/ha range from 1.7 to 3.0 tons/ha for split broadcast urea and from 2.7 to 3.8 tons/ha for deep-placed urea among the eight locations.

At four locations about 1 ton/ha more paddy was realized from 120 kg N/ha of deep-placed urea than from split broadcast urea. The added yield gives additional net returns of about $100/ha. Differences in yield responses were about 0.5 ton/ha from applications of 90 kg N/ha in favor of deep-placed urea at three other locations, which gives about $45/ha greater net returns. Estimated savings in N through deep placement are 50 kg/ha to produce a yield response of 1.5 tons/ha for locations giving the greater response difference and 15 kg/ha at locations giving the smaller response difference.

The potential for improving nitrogen use efficiency for boro rice in Bangladesh appears to be great. If deep placement were adopted by farmers for 0.5 million hectares of boro rice (about one-third of the area) and average benefits were similar to those for the group of experiments giving the lower response difference, Bangladesh could expect an additional 238,000 tons of paddy annually and an aggregate additional benefit to farmers of more than US $20 million (average rate of nitrogen assumed to be 60 kg/ha). Alternatively, current production could be maintained with 16,000 tons less urea.

Results of urea deep-placement research were discussed during a national workshop conducted at the conclusion of the agronomic services project in 1985. Two of the recommendations that workshop participants made at that time imply the principal direction in which they thought future deep-placement work should go. They are: (1) During dry seasons experiments on deep placement should be done directly in farmers' fields on an expanded basis and (2) Socioeconomic studies should be conducted to determine the potential for farmers' accepting the practice of deep placement.

Personnel Training

Technology transfer through personnel training is an important component of the BADC/IFDC marketing consultancy agreement. In 1985 in-country training was provided to 103 members of BADC's fertilizer marketing staff. A Fertilizer Marketing Management Workshop was conducted for 26 BADC divisional and regional managers to raise the level of understanding and to improve participants' proficiency in managing newly instituted changes in the marketing systems by applying recognized marketing management techniques. Three 1-week management workshops were presented for 77 assistant warehouse managers to review job responsibilities and performance as affected by newly introduced stock control and warehouse management systems.

Additionally, with assistance from IFDC, a BADC senior warehouse construction project manager took part in a 9-month U.S. Department of Agriculture Graduate School-sponsored program on International Management Development. The participant successfully completed the course and was awarded a Master of Science in Administration degree from a U.S. university. Arrangements were made for the

enrollment of a senior BADC official to attend a 2-week course in "International Purchasing, Procurement and Stores Management" conducted by the World Trade Institute in New York.

IFDC staff arranged and participated in a 2-week fertilizer marketing study tour of the U.S. fertilizer producers and marketing organizations for the above-noted BADC senior official and a member of the USAID/Dhaka staff. The tour objective was to study marketing management techniques in the United States and their possible application in Bangladesh.

Indonesia

The Indonesian Fertilizer Efficiency Program is assisted through the Agency for Agricultural Research and Development-IFDC Joint Project on Efficient Use of Fertilizer. The project is partially funded by the Australian Development Assistance Bureau. IFDC, through the Centre for Soils Research (CSR), advises and assists three working groups (lowland, upland, and socioeconomic). Priorities of the project are:

1. Research on determining the fate of fertilizers in soil and factors influencing their efficiency.
2. Identification, development, and evaluation of new and/or improved fertilizer products or fertilization practices that are appropriate for Indonesian conditions and which will result in more efficient use of fertilizer.
3. Development, evaluation, and demonstration of systems including those centered at the village level that will ensure transfer of technology to increase fertilizer use and efficiency and benefit the farmer.
4. Research that identifies the economic and social benefits and consequences to the farmer and the nation that are likely to accrue as a result of adopting technologies that increase fertilizer use efficiency. Training of an appropriate number of Indonesian scientists and technical personnel in areas related to fertilizer efficiency.

Lowland and Socioeconomic Working Groups

These two working groups are combining efforts to improve N use efficiency for flooded rice. The broad objectives of this effort are: (1) to define the nature of rice yield responses to urea deep placement relative to commonly used urea fertilization practices and (2) to determine the potential for farmer adoption of the practice. Activities to meet these objectives are conducted in three pilot areas: Subang, West Java; Klaten, Central Java; and Ngawi, East Java. Activities include: farmer surveys, conduct of trials in farmers' fields, agroeconomic analysis, and testing of prototype mechanical fertilizer-placement applicators.

During 1985 a survey was conducted of 62 farm households in the Ngawi area, which included 112 fields for rice cultivation during the 1984/85 wet season. All farmers reported that urea was broadcast onto drained fields, and the mean rate was 309 kg/ha. Sixty-six percent of the fields received some urea at transplanting, 86% at 2 weeks after transplanting, and 87% near panicle initiation. Composted rice straw was applied to 64% of fields at an average rate of 2.5 tons/ha. N and P were applied to all fields and K to 64% of the fields.

The average area planted to rice was 0.79 ha, and the average field size was 0.47 ha. Fifteen percent of the farmers owned the entire rice-planted area, 16% cultivated both owned and nonowned land, and 69% cultivated all their rice land under sharecropping and/or a fixed-rent cash basis. All farmers planted improved varieties. Paddy sale prices ranged from US $0.08-$0.12/kg, with an average of US $0.10/kg while urea was slightly cheaper than this.

Field trials consisting of a central replicated trial and three dispersed replicates within a 2-km radius were conducted during the 1985 wet and dry seasons. In the central experiment three split broadcast and basal deep point-placed urea trials were compared at rates of 0-174 kg N/ha both without and with rice straw compost at a rate of 2.5 tons/ha. Three split and two split broadcast and basal deep point-placed urea satellite trials were compared at rates of 0-174 kg/ha.

An Indonesian worker puddles a rice paddy.

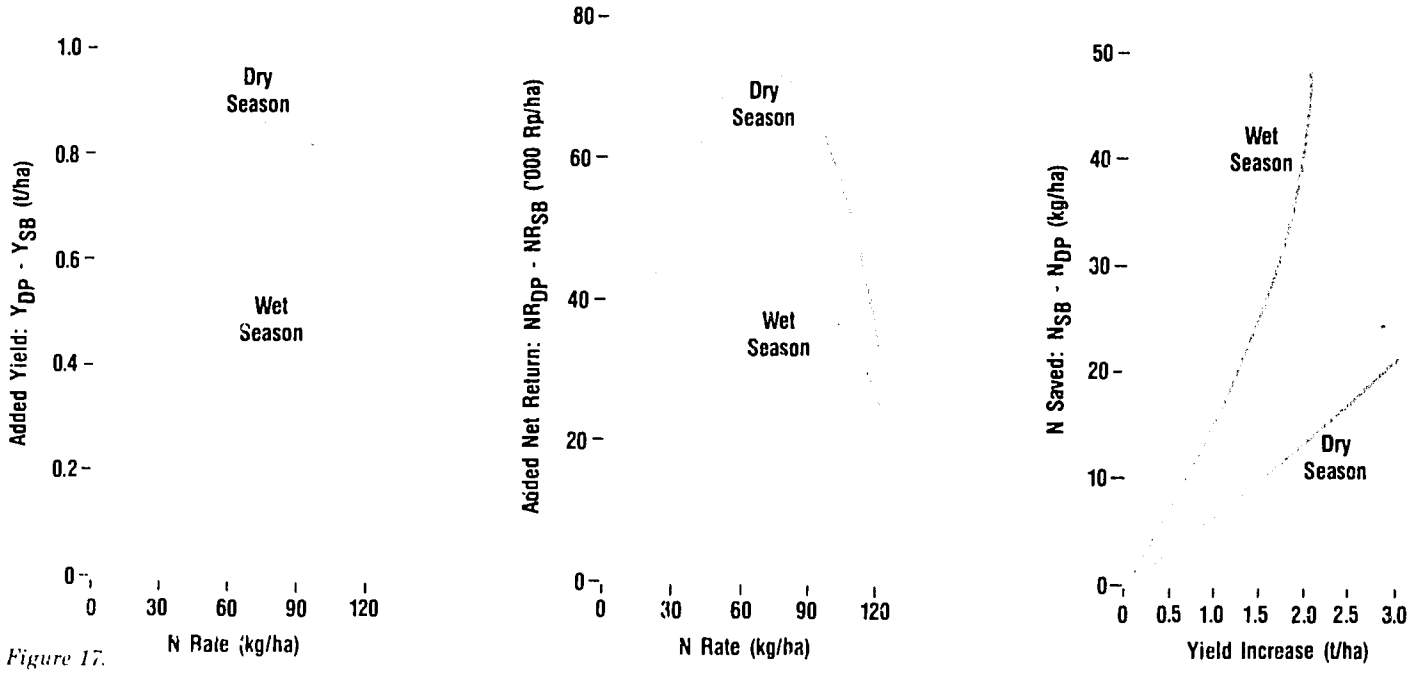


Figure 17.
Estimated Added Yield, Added Net Returns, and Saving of Nitrogen Gained by Deep Placement (DP) as Compared With Split-Broadcast (SB) Urea, Wet and Dry Seasons, 1985, Ngawi, Indonesia.

Application of 2.5 tons/ha of composted rice straw has had no effect on rice yield response to N by either method of application. Responses to two and three split broadcast applications of urea were similar during both seasons, but deep placement was superior to broadcast applications in both seasons. Maximum yield difference (0.5 tons/ha in wet season and 0.8 tons/ha in dry season) from split-broadcast and deep-placed urea occurred at an N rate of about 75 kg/ha (Figure 17). This resulted in added net returns from deep placement as compared with split broadcast of US $36/na in wet season and US $62/ha in dry season. Since additional investment is about US $9/ha, the benefits from deep placement appear to be quite profitable, particularly for the owner farmer. The next step is to determine the benefits that farmers can obtain and monitor their attitudes toward accepting the practice.

Upland Working Group

The principal purpose of the upland component of the project is to evaluate constraints to food production on Ultisols and Oxisols, which are important for government settlement projects. The major issues addressed are the potential of phosphate rock and PAPR as P sources, crop responses to P and lime, and evaluation of crop varieties and their responses to P. Each is studied in relation to soil characteristics and climatic conditions.

About 120 crop harvests have been made from six types of experiments conducted at seven locations between 1982/83 and 1984/85 crop years. These experiments are managed by CSR and by the Central Research Institute for Food Crops.

At all locations experiments are conducted with a crop rotation (rice-soybeans-cowpeas). Additionally, at Nakau experiments also are conducted with a cropping system consisting of (rice/maize/cassava)—(soybeans/cassava)—(cowpeas/cassava) mixture and sequence.

Although analyses of data are incomplete in terms of defining relationships between yield responses and soil characterstics and climatic conditions and of estimating economic returns, certain conclusions are evident. They are:

1. Central Florida phosphate rock (medium reactivity) when applied within the seed row is a suitable source of phosphorus for soybeans and cowpeas, which are seeded 4-6 months after application of phosphate rock. But phosphate rock is somewhat less effective than TSP for rice seeded immediately after application.
2. From TSP applied in the seed row at 20 kg P/ha, it is reasonable to expect returns of 30 kg of rice, 20 kg of soybeans, and 5 kg of cowpeas for each kilogram of P applied.
3. Maize gave consistent and large responses to P at Nakau (only site grown). Responses to lime were consistent at 20 kg P/ha from TSP but eliminated by additional P (50 kg P/ha from phosphate rock). Liming probably increased P availability to some extent.
4. Soybeans gave consistent responses to lime while rice and cowpeas did not.
5. The rainfall pattern influences the availability of soil moisture which, in turn, influences crop yield and responses to P.
6. Long-term experiments are necessary to determine the effects of variation in rainfall patterns on crop yields and responses to nutrients and to monitor changes in soil fertility status.

Mali

The urgent need to increase food-crop production in the Sahel region is par-

ticularly acute in Mali where the population growth rate in the cities is 6.06% but only 1.51% in rural areas. There is also an increasing gap between the need for food and the capacity to produce that food, and steps must be taken to increase yields.

Although in the Sahel the most limiting factors are rainfall and poor soil moisture regime, the low fertility level of the Malian soils requires additional fertilizer nutrients for sustained high-yielding agriculture. The soils of Mali have a coarse texture, low P status, low organic-matter content, low cation exchange capacity, but usually adequate base saturation. In addition, soils are generally acid and have a low P-retention capacity, which are favorable conditions for the use of less soluble P sources such as ground phosphate rock. The P fertilizers currently used in intensive farming systems in Mali are imported and are both expensive and a drain on foreign exchange reserves. Since Mali has a commercial-size deposit of 20 million tons of phosphate rock, efficient agricultural use must be made of this natural resource.

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 Rural has made an in-depth study of the value of Tilemsi rock-based P 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 is ongoing, is based on farmers' field trials.

The overall objective of the study is to evaluate the agronomic and economic efficiency of indigenous phosphate-based fertilizer sources and to define their management in different agroclimatic regions of the country.

Results from these experiments will assist the Government of Mali in the development of a least-cost strategy designed to supply farmers with indigenous P fertilizers and thereby increase both crop production and farmers' income, as well as reduce spending of foreign exchange in buying costly imported P fertilizers.

The overall planning and methodology developed in conducting these projects can be used as a model for developing national programs in other countries of the sub-Saharan region.

Project Implementation

The phosphate project integrates both research station and farm-level experimentation that result in strong involvement of national research and extension institutions. Experimental trials were conducted at 10 selected research station sites representing the major soils, climatic patterns, and cropping sequences in Mali. Four types of experiments were designed as follows:

1. Response to annual application of phosphate rock, PAPR, and TSP at four application rates, supplementary to a one-time basal application of phosphate rock at three application rates.
2. Response to basal application of phosphate rock, PAPR, and TSP at five application rates.
3. Response to annual application of phosphate rock, PAPR, and TSP at five application rates.
4. Response to annual application of phosphate rock, PAPR, and TSP at four application rates and comparison of three placement methods: broadcast, banded, or hill placement.

The farm-level experimental design used consisted of four treatments. They were a fertilizer formula (N, P, K, S, and boron) applied at a rate commonly used by most of the farmers (150 kg fertilizer/ha or 33 kg P_2O_5/ha); Tilemsi phosphate rock at two rates (60 kg P_2O_5/ha and 120 kg P_2O_5/ha); and a phosphate check plot. All four plots received equal rates of application of N, K, and S. The treatments were randomly distributed in a block with no replications. The treatments were applied to a field in which the management level maintained was that practiced by most of the farmers of the region. Yield variations across different areas and rainfall patterns were evaluated. All experiments were designed to develop recommendations on fertilizer practices in various cropping systems based on economic benefits of fertilizer use. Fertilizer rates were assumed to represent a recommendation range for the specific area, cropping systems, and crop management practices.

Factors to be measured are usually classified as dependent and independent variables. For the present study, dependent variables were grain and seed yields for cereals, cotton, and groundnuts. Independent variables were classified as controlled and uncontrolled. Controlled variables, those selected and maintained fixed during the experiment, were: P sources and rates, time of P application, and methods of application. Uncontrolled factors were those related to soil and rainfall variables. These factors are assumed to change from site to site, and although they are not controlled by the farmers, they interact with the controlled factors and in general with farmer practices thus influencing yields. Introducing these variables in a response model provides a useful tool for extension workers and researchers to evaluate experimental results, validate alternatives for crop production, and provide them with a basis for sound recommendations.

Results: Effect of Phosphate Rock on Various Cropping Systems

1. **Cotton-Maize System**

   From this series of experiments it was concluded that in a cotton-maize cropping system similar average yields can be obtained with phosphate rock as with compound cotton fertilizer when considering only the P source variable (N, K, and S were applied uniformly). Moreover the yield responses are very homogeneous within given agroecological zones, and sound recommendations can be developed.

   Cotton response due to phosphate rock is excellent and improves over the years; this indicates a very good residual effect of phosphate rock. The impact of crop management practices such as planting

date, plowing date in connection with application, and incorporation date of phosphate rock has been emphasized and will be considered in the future for the final recommendation. There is, however, sufficient information at this stage to provide the Government of Mali definite recommendations on the use of phosphate rock in the CMDT zone.

In addition, annual applications of phosphate rock now make sense because both cotton and maize are considered as cash crops. Annual application rates of 40-55 kg P_2O_5/ha, depending on the region, can be recommended. Maximum net profit is, however, obtained by using 55-84 kg P_2O_5/ha, depending on crop and agroecological zone.

The results on a cotton-sorghum rotation suggest similar conclusions, but in the driest areas there seems to be little or no alternative to soluble phosphates for maximum yields.

Malian field workers apply phosphate fertilizer to a field prior to planting.

2. **Maize-Groundnut System**

From experiments where test crops were maize and groundnuts grown in rotation, it was concluded that, as in the cotton-maize system, there is a good response of maize to phosphate fertilizer application and Tilemsi phosphate rock in particular. However, groundnuts showed little or no response to any source of phosphate. Although benefits of phosphate rock applications to groundnuts are not shown on our research station experiments, the Semiarid Food Grain Research and Development program and the Operation de Developpement Integre de Production d'Arachide et de Cereales—the major extension service dealing with groundnut production in Mali—report groundnut response to phosphate rock in farmers' field. This shows that farmers' field testing is necessary for full evaluation of any response to phosphate rock in a maize-groundnut cropping system.

Nevertheless, since maize is the most promising crop in this system and provides the best response, phosphate rock should be applied on that crop. Depending on rainfall and/or cash available to the farmer, application of phosphate rock at rates of 60 to 120 kg P_2O_5/ha can be recommended on the maize. This treatment should be followed by 30 to 60 kg P_2O_5/ha as Tilemsi phosphate rock, depending on rainfall and initial phosphate rock application, on each of the following maize crops in order to sustain high yields of the maize. As in the cotton-maize system supplementary N, K, and S nutrients were applied to allow maximum crop development, and only P response was considered in the analysis.

3. **Sorghum or Millet-Groundnut System**

Climatic constraints very often limit crop response to fertilizer in general and to phosphate rock in the sorghum and millet cropping areas in particular. Therefore, soluble phosphate sources were found to give generally better crop response than phosphate rock. However, when climatic conditions are favorable, the phosphate sources provide similar yields. In order to secure a better return on investment and reduce risks, it is a common practice for farmers to reduce application rates. Farmers would then only obtain, in a good year, net returns of less than $30/ha, which is not economically attractive. However, there is indication that applications of phosphate rock may stabilize yields over years. As such, Tilemsi phosphate rock can be seen as an investment for security.

Indeed, the residual effect of phosphate rock application allows Tilemsi phosphate rock to be, over the years, at least as efficient as soluble phosphate despite possible adverse climatic factors. As a result although phosphate rock may need to be supplemented in the first 2 years by soluble P, which may not always be economical depending on climatic conditions, the P fertilization requirements for sorghum and millet can be met in the long run by Tilemsi phosphate rock applications alone.

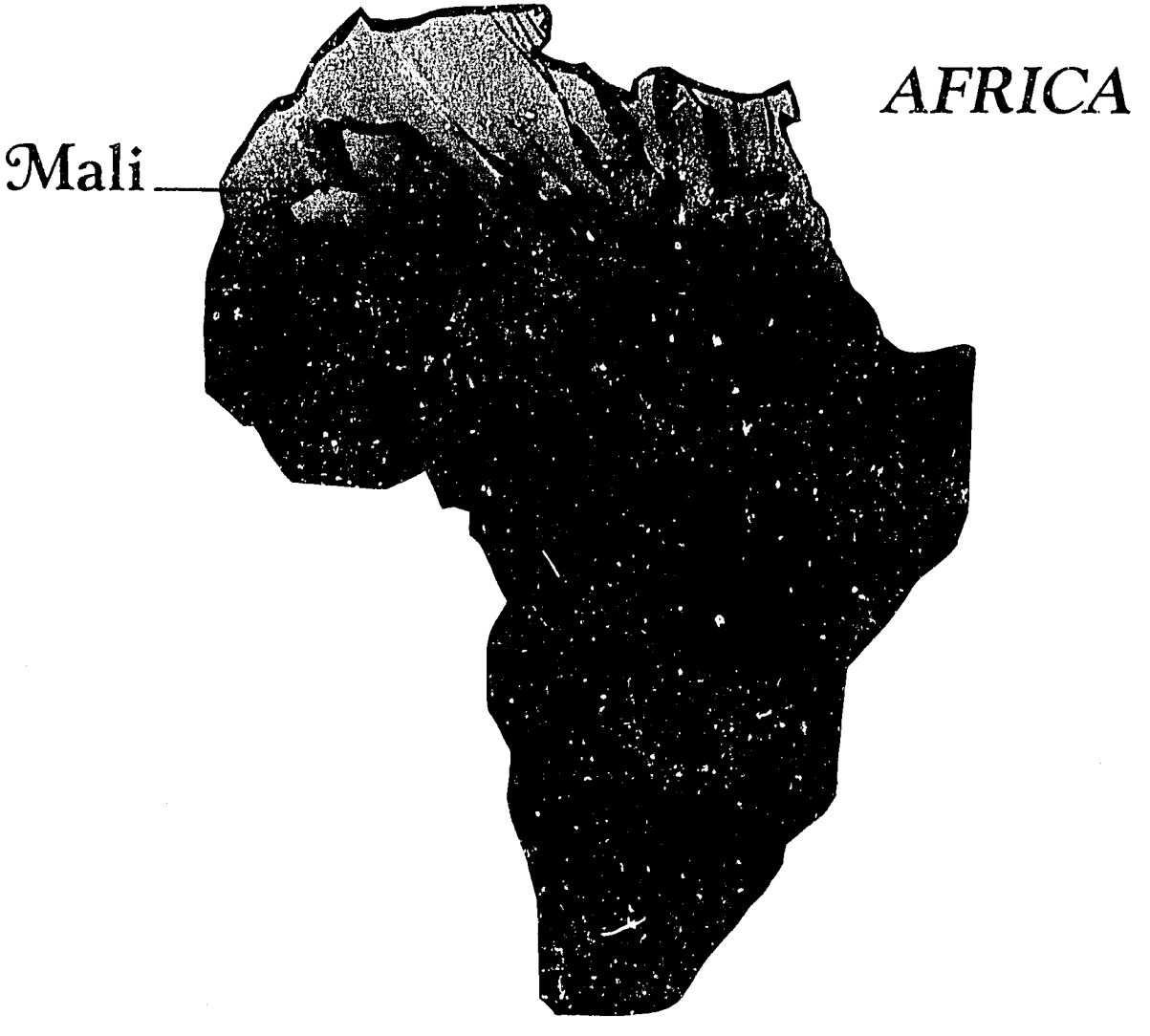
As in the other cropping system involving groundnuts, response of groundnuts has been very limited in experiment station trials, but farm-level results reported outside this project seem to indicate a response in farmers' fields. Farm-level trials are required for development of

sound recommendation on this cropping sequence.

4. **Irrigated Rice**

In the soil conditions of Kogoni, only limited response to phosphate rock can be anticipated in the year of application. However, results showed that as of the second year phosphate rock can successfully be used under the conditions existing at the Kogoni station, and higher net returns are obtained by using phosphate rock rather than a soluble P. In addition, phosphate fertilizer efficiency can be maintained fairly constant by only annual application of phosphate rock; this indicates that the whole phosphate fertilization of rice, under the conditions at the Kogoni station, can be done by using phosphate rock.

However, results also indicate that, in order to obtain higher net returns and reduce risk, one heavy initial application of phosphate rock rather than the same application split annually should be recommended.



Technical Assistance

IFDC's technical assistance activities have shown a distinct evolutionary pattern over the years, according to Dr. Dennis H. Parish, Director of the Outreach Division. Initially, involvement in Latin America accounted for a major share of IFDC's activities. Later, emphasis shifted to Asia with major involvement in Bangladesh, Indonesia, and the Philippines. More recently, joint activities with India have developed.

In Africa the pattern of technical assistance activities, apart from Egypt with which IFDC has had a long and fruitful cooperative relationship, has been different. In the mid-70s there was heavy involvement in terms of country fertilizer-sector studies in the Sahelian zone. However, close working relationships with specific countries expanded only slowly from 1980 onward when IFDC developed ongoing involvement with Nigeria and Mali. Programs are now evolving with many African countries. This movement of the center of gravity of IFDC's technical assistance activities from Latin America to Asia to Africa reflects essentially the progress made in agricultural production and particularly in the progress towards food self-sufficiency. Africa's needs are now by far the most urgent.

In performing its technical assistance activities, IFDC can do so in a nonbiased way since it sells no particular technology or methodology. Of uppermost importance is the benefit to the country and ultimately to the small farmers—the backbone of agriculture in most developing countries.

According to the Director of the Fertilizer Technology Division, Owen W. Livingston, the recent downturn in the fertilizer sector has stimulated interest in the improvement of efficiency in producing, storing, and handling products; in devising more cost-effective marketing systems; in improving fertilizer chemical and physical quality; and in using one or more local resources to reduce imports.

Africa

Agronomic and Economic Study of Fertilizer Use in Egypt

During 1985 IFDC staff analyzed the agronomic and economic situation in Egypt with respect to nitrogen fertilizer use and projected demand. This project was one component of a study entitled "Preinvestment Analysis of Alternatives for Increasing Nitrogen Fertilizer in Upper Egypt" conducted by Stone and Webster Management Consultants.

In Egypt most of the 2.48 million irrigated ha is doublecropped; maize outranks all other cereals in area and cash value. During the period 1973 to 1983, N fertilizer substantially increased yields. By combining five irrigations with 200 kg/ha of N per hectare, yields of maize in excess of 8,020 kg/ha can be attained with a benefit:cost ratio of 8.3 at unsubsidized prices by the year 2000.

It was estimated that 20.4% of the national N demand in the year 2000 would be in Middle Egypt and 24.7% in Upper Egypt. This amounts to 214,000 mt and 258,000 mt of N for these areas, respectively.

Kenya Marketing Study

USAID through the IRI Research Institute of Stanford, Connecticut (U.S.A.), commissioned IFDC to conduct an evaluation of its agricultural development program in Kenya. The objectives of the USAID program are to (1) promote widespread distribution of fertilizer through involvement of the private sector, (2) make fertilizers available to small farmers on a timely basis, and (3) increase fertilizer use by small farmers.

Specific objectives of the evaluation were to determine:

1. Degree of progress in the development of a system to move donor-provided fertilizer to the private sector.
2. Degree of progress in establishing a price mechanism that serves the interest of the farmers, fertilizer distributors, and the Government of Kenya.
3. Progress in the timely movement of local currency generated from fertilizer sales to the separate special account.
4. Effective management of local currency deposited in the separate special account.
5. Effectiveness of the Fertilizer Advisory Committee in helping to ensure that appropriate types and quantities of fertilizer are imported into Kenya on a timely basis.
6. Efficiency of the current fertilizer allocation system.
7. Effectiveness of the Fertilizer Advisory Committee in bringing the

interests of private-sector fertilizer distributors to the attention of the Government of Kenya.

Even though the USAID program had been in operation slightly less than 1 year at the time of the IFDC evaluation, a considerable amount of progress was made during the initial stages. So far the USAID program has imported and distributed 50,000 tons of DAP. During March and April 1985, 20,800 tons were imported. This fertilizer was distributed to the major maize- and wheat-producing areas during the long-rain planting season, March-June. The evaluation documents the movement of this fertilizer and the implementation of the program. It also provides recommendations for improved implementation based on interviews with distributors, consultants, and Government of Kenya planners.

After only 10 months of operating the program, USAID has achieved one objective of the agricultural development program in Kenya, that is, to obtain private-sector involvement in fertilizer distribution. Previously, the Kenya Farmers' Association virtually had a monopoly in donor fertilizer distribution. Donors provide 40%-50% of annual fertilizer imports into Kenya. USAID was successful in distributing all of its DAP through 16 private-sector firms. The survey found that the supply of all fertilizers was extremely limited at the small farmer level.

The objectives of the agricultural development program—to make fertilizer available to small farmers on time and to increase fertilizer use by the small farmers—have not been fully met. However, progress toward reaching these objectives has been made. In a situation where supply is short, the larger, more aggressive farmers will usually seek out the fertilizers for purchase. The distribution system will also tend to serve the large farmers at the expense of the small farmers. To meet these objectives, a highly disciplined distribution system will be required.

The findings of the study team justify USAID's introduction of a smaller bag of fertilizer, perhaps 10 kg. Several stockists are now selling DAP by the kilogram. Many small farmers cannot afford to purchase a 50-kg bag and prefer a smaller bag. The most appropriate small bag size has not been determined.

IFDC technical assistance projects will ultimately help to keep bountiful supplies of food available, as seen in this Kenyan market scene.

Educational programs directed toward improving fertilizer marketing at the distributor and stockist level and use at the farmer level are limited. The lack of sufficient educational and promotional programs is one of the weak spots of the marketing system.

The study found that distributors of USAID DAP were not attempting to carry out all marketing functions to a satisfactory level. The study included recommendations for improving marketing by the distributors of USAID fertilizers.

Nigeria Marketing Study

The Federal Republic of Nigeria requested IFDC to conduct a feasibility study for commercializing fertilizer marketing in Nigeria. The study contains procedures for developing a fully self-supporting system along commercial lines. More specifically, the study:

1. Outlined and described an organizational structure and all component parts required for efficient operation.
2. Determined personnel and funding requirements.
3. Made provision for phasing in the system.
4. Identified institutional linkages required for efficient operation of the system.

The cost of marketing fertilizers has become a burden to the Government of Nigeria. In earlier years when consumption was small, the drain on foreign exchange and other needed national programs could be managed. In 1984, with the importation of 835,000 tons of fertilizer, the direct cost to the Nigerian Government exceeded ₦90 million (US $101.7 million). This does not include other excessive indirect costs represented by uncollectable sales, physical losses of product, warehousing, personnel of involved organizations, etc. There is an urgent need for a self-supporting fertilizer marketing system.

Fertilizer consumption in Nigeria is relatively low, and nutrient consumption has remained about constant since 1981. Fertilizer consumption

needs to be increased through more promotional activities and, in turn, food production would be increased.

Currently, a physical distribution system is being used rather than a complete marketing system. This results in a higher cost than is necessary. The Government of Nigeria is considering the possibility of discontinuing its involvement in the fertilizer market by assigning it to a commercial organization that can be self-supporting, increase fertilizer consumption, help to make farmers aware of the proper use of fertilizers, and increase food production. When it is fully implemented, the recommended commercial fertilizer marketing system that was designed especially for Nigeria can accomplish these goals.

Nigeria Fertilizer Transportation and Storage Study

At the request of the Nigerian Federal Ministry of Agriculture, Water Resources and Rural Development, systems for port handling, transportation, and storage of fertilizers were studied. Plans were developed for the distribution of fertilizers from imports and from local production. Estimates of consumption were made.

Consumption on a nutrient basis is forecast to increase from 221,000 tons in 1984 to 469,000 tons in 1988, for an annual growth rate of 20.7%. On a product basis, consumption is forecast to increase from 606,000 tons in 1984 to 1,002,000 tons in 1988. This represents a growth rate of only 13.4% because of a switch to fertilizers of higher concentration.

The transport infrastructure was studied in detail. Port facilities are adequate for handling projected imports. The road network and road transport fleet are adequate for primary fertilizer movements. Because of equipment constraints, railway capacity cannot currently be used fully and is not adequate for present fertilizer movement requirements. This is due largely to shortage of locomotives.

A network of 191 primary distribution points (PDPs) spread throughout the country was identified. The recommended marketing system envisages direct delivery to a considerably larger number of delivery points, perhaps 2,200 for the 1988 offtake level.

These Nigerian women are threshing maize.

Comparative shipping costs for various sizes of vessels and handling costs through the ports were calculated to define relative landed costs. These were compared with the differential land transport costs to determine the optimum ports to serve each state. Shipping requirements were then developed for each product for each year. These were then aggregated and rationalized into an overall, detailed ship arrival plan, compatible with port handling capacities, land transport capacities (particularly rail), and the necessary seasonality of delivery to the states. Separate calculations were made for the PDPs that are most favorably supplied by rail.

In considering supply by rail from Onne, the case for provision of a rail connection into the factory was studied. The Nigerian Railway Corporation had estimated the capital cost at approximately ₦10 million (US $11.3 million). The additional revenue to that corporation would justify installation of the siding and the motive power stock necessary. Dispatch of two trains per day on a regular basis, with onward movement by truck to delivery points, is recommended. This would save about ₦5 million (US $5.65 million) per year compared with direct delivery by road and would benefit the railway company's operating revenues.

A total fertilizer storage capacity of 1.13 million tons was identified in the country—half at PDPs and the other half in secondary and associated stores. This is more than adequate to meet requirements on both a national basis and at the state level.

Supply balances were considered on the basis of Onne production forecasts from the National Fertilizer Company of Nigeria, Ltd. (NAFCON). The Onne plant will produce urea and can produce either compound fertilizer or DAP on the granulation unit. The Onne granulation plant is expected to run at full capacity on compounds, and all DAP will be imported. At 1988 levels of consumption and full output this corresponds to a surplus of over 100,000 tons of urea and a shortfall of a similar quantity of compound fertilizer, which will have to be imported.

In this situation, it is recommended that the possibility of installing a blending unit at Onne should be studied.

In developing optimum plans for future physical distribution of fertilizer, a computer-based origin-destination matrix was developed for supply from all sources to all designated PDPs. Least-cost routes were defined. A stocks-use program was also developed on an overall national basis.

Transport costs for the total system in 1984 were calculated at ₦62.8 (US $70.9) per ton. This compares with some ₦54 (US $61) per ton calculated for the optimized distribution plans developed for 1986-88. Savings arise partly from additional use of rail transport and partly from use of optimum ports to the maximum practical extent. The greatest savings arise from effective management of the system.

Capital requirements for development of the fertilizer physical distribution and handling system are minimal. Investment required for provision of a rail spur to the Onne factory and for provision of the necessary locomotives is the responsibility of the Nigerian Railway Corporation. These investments should, however, be strongly promoted, since they are in the national interest. Current highway development plans appear adequate, and it is anticipated that availability of trucks from the private sector will continue to be sufficient to satisfy all fertilizer transportation requirements.

Overall organization and control of the future system was outlined; consideration was given to the management organization, interrelationships, and responsibilities.

Asia

Malaysia—FPM Sendirian Berhad Granulation Project

Since its creation, the Malaysian fertilizer-producing company, FPM Sendirian Berhad, has used the services of IFDC to develop and refine its technology. This Malaysian enterprise uses an NPK granulation process specifically devised by IFDC for its Pasir Gudang factory.

During the early phases of this company's industrial life, IFDC was instrumental in its startup, from reviewing and commenting on the detailed engineering package provided by an engineering company and onsite assistance during the construction of the facility to the training of the operating personnel and supervision of the startup operations. Since then IFDC has continually assisted this company in many technical and managerial aspects, particularly in helping FPM fine tune its operation to increase its earnings and enhance its product quality.

During three plant visits in 1985, IFDC engineers provided assistance in initiating an improved on-stream sampling program, develop grade-change formulas, streamline the formulation adjustment procedures, implement a quality assurance program, improve their nongranular bulk-blend production, and upgrade the product bagging system. Also, several computer programs were prepared for performing statistical analysis of laboratory results and preparing a yearly budget of variable costs.

Philippines—Assistance to PHILPHOS

A bench-scale phosphoric acid concentration unit of the type used at IFDC was assembled, tested, and shipped to Philippine Phosphate Fertilizer Corporation (PHILPHOS). This unit is now operational.

At the request of PHILPHOS, ten phosphate rock samples were analyzed by IFDC. A fertilizer specialist visited the PHILPHOS production facility for 6 weeks to render assistance on methods of chemical analyses and to evaluate equipment needs of the analytical laboratory.

Latin America

Venezuela—PEQUIVEN Technical and Economic Process Evaluation

At the request of Petroquimica de Venezuela S.A. (PEQUIVEN), an IFDC engineer visited the Moron complex to assist in a techno-economic process evaluation for a 300-mtpd urea granulation unit. PEQUIVEN is considering the partial or total conversion of the existing urea prilling plant to the production of granular urea. The granular urea will be mixed with DAP and KCl for the production of bulk-blended fertilizers since the particle size of their prilled urea is too small for suitable quality blends. The main activities of the technical assistance visit were to jointly work with a PEQUIVEN evaluation team (Phase I) and then prepare and submit a process comparison report, which included the total investment cost and total incremental conversion cost estimates for the selected urea granulation processes.

In addition, the IFDC engineer provided technical assistance to several plants that constitute the Moron complex.

Chile—Assistance on Bahia Inglesa Phosphate

In prior work a flowsheet was developed to beneficiate the Bahia Inglesa phosphate ore. The sponsor decided to perform additional tests through the Instituto de Investigaciones Technologicas in Santiago. They requested a minerals engineer to provide onsite assistance to refine their research activities. During his assignment in pilot-plant tests, they were able to produce a concentrate containing about 26% P_2O_5 and 11% silica at 57% recovery, starting with an ore containing 17%

P_2O_5 and 25% silica. The end use of the concentrate is not certain, but it is being considered for TSP. The company decided not to produce phosphoric acid from this ore.

Peru Fertilizer Marketing Study

At the request of USAID, IFDC staff visited Peru to conduct a fertilizer marketing study for that country.

During the course of the study, the IFDC team identified two major fertilizer marketing constraints that are restricting increased fertilizer usage. First, fertilizer retail prices are excessively high compared with prices received by farmers for their crops. In addition, there is almost a total lack of promotion to encourage farmers to use fertilizers or to show or tell them how to use fertilizers correctly or efficiently.

Additional marketing-related constraints include the absence of a national fertilizer strategy, a shortage of retailers, the lack of a national planned fertilizer minimum inventory level, the absence of national fertilizer specifications and labeling laws, an unbalanced usage of fertilizer, and high foreign exchange cost of imported phosphates.

Some possible solutions to these constraints were suggested. It was proposed that a coordinated national promotion and research program be developed to help farmers use fertilizer to increase production, productivity, and farm income. A multidisciplinary program to develop the Bayovar phosphate rock for direct application was also suggested. It was proposed that a technical committee draft a national fertilizer specifications and labeling law. Another technical committee was proposed to develop a national fertilizer sector objective and strategy.

Haiti—Engineering and Marketing Assistance

Agricultural Services S.A. (ASSA) operates the only fertilizer plant in Haiti, and they produce NPK fertilizers for the Haitian market by bulk blending imported raw materials. ASSA's production facilities, established in 1982, are located on rented property quite distant from a deep-water port and a major expanding market region. These factors limit ASSA's ability to expand their services to the Haitian farmers and provided the reason for ASSA to consider relocation and expansion of their production facilities.

Hatch Associates Ltd. (Hatch) of Canada was employed by ASSA to study the feasibility of the envisioned relocation and expansion. IFDC fertilizer marketing and production specialists worked closely with Hatch in developing the marketing, production technology, and production cost components of the study.

The results of the study indicate that the envisioned relocation and expansion are feasible, and project funding alternatives are currently being evaluated.

Other

Hungary—Fluid Fertilizer Study

An IFDC staff member assisted a World Bank team in the assessment of content and scope of one of the components of a loan requested by the Government of the Hungarian People's Republic (GOH) for an agricultural project. The total project, the Crop Production Improvement Project, is to implement the objectives of the seventh 5-year plan (1986-90) developed by the GOH to improve the country's foreign trade balance position by increasing exports, reducing imports, and improving efficiency. The project component that IFDC helped assess calls for the construction of ten multinutrient fluid fertilizer plants. These plants would require a total fixed investment of about 491.3 million Ft (US $9.3 million) and would supply the fertilizer requirements of a farming area of 350,000 ha.

The analysis of this project component showed an overall financial benefit of 234.8 million Ft/year (US $4.4 million/year), derived mainly from expected crop yield increases. These higher yields would be the result of (1) more uniform distribution of nutrients, (2) improved availability of the nutrients contained in the fluids, and (3) decreased compaction of the soil due to fewer fertilizer application trips across the field than when single-nutrient solid fertilizers are used.

The projected ten fluid fertilizer plants were therefore considered beneficial, and it was recommended to the World Bank to include this component in the loan.

Kuwait—NPK Fertilizer Project

A U.S. company engaged the services of an IFDC engineer for planning of an NPK project in Kuwait. They requested assistance in using urea in NPK formulas such as 17-17-17.

The assistance included arranging a visit to the FPM Sendirian Berhad urea-based NPK granulation plant in Johor, Malaysia. IFDC assisted FPM previously, and many of the FPM plant and process design features were recommended for incorporation into the Kuwait project.

Training Programs IFDC's training programs are designed to build and strengthen the technical and managerial capabilities of developing-country personnel in a broad range of subjects dealing with fertilizer production, marketing, and use.

IFDC offers both group and individualized training. The training programs are partially supported by UNDP; other funding agencies also support programs. For example, during 1985 the International Fund for Agricultural Development supported a program in the Cameroon; UNDP sponsored the Caribbean workshop, which was also supported by the Canadian International Development Agency and USAID; and GTZ supported a phosphate training program. Those programs of global impact are usually conducted at Headquarters and/or other locations in the United States. Programs of regional interest are carried out in conveniently accessible locations in Africa, Asia, and Latin America. They often involve cosponsorship and/or participation of international, regional, and national organizations involved in fertilizer sector development. For example, during 1985 the Institute of Agronomic Research, Ministry of Higher Education and Scientific Research, Government of Cameroon, cosponsored a workshop in that country. The Centre for Soil Research, Agency for Agricultural Research and Development, Ministry of Agriculture, Government of Indonesia, cosponsored a training program in that country. A fertilizer production training program, conducted in India, Indonesia, Malaysia, and Thailand, was cosponsored by the Fertiliser Association of India and Assosiasi Produsen Pupuk Dan Petrokemia Indonesia.

During 1985 IFDC organized and conducted eleven group training programs. In all, 251 participants from 59 countries took part in these 11 training programs.

Group Training

A brief synopsis of each of the 1985 group training programs follows.

1. **Fertilizer Efficiency Research and Technology Transfer Workshop in Africa**

   Location—Douala, Cameroon
   Number of Participants—31
   Countries Represented—15

   Target Audience—Directors of fertilizer research organizations and extension agencies.

   Objectives—To review state-of-the-art in soil fertility management and role of fertilizer in food production in Africa. To formulate guidelines for designing effective fertilizer efficiency research and technology transfer strategies.

   Content—Overview of advances in fertilizer efficiency research and technology transfer, including integrated plant nutrition systems; soil, crop, and fertilizer-use related socioeconomic research; constraints to development and transfer of fertilizer recommendations; and strategies for adoption of improved fertilizer practices.

   Methodology—Presentations and discussions followed by small group review and analysis and preparation of suggested policy options for resolution of identified issues. These were presented to and approved by the participants.

2. **Fertilizer Production Training Program for Asia**

   Location—India, Thailand, Malaysia, and Indonesia
   Number of Participants—18
   Countries Represented—7

   Target Audience—Fertilizer plant managers, production superintendents, and first-line production supervisors.

   Objectives—To strengthen the technical knowledge and practical skills in fertilizer production technology by first-hand observation of successful plant operations in subject countries. To identify and discuss solutions to problems in fertilizer production and plant operation.

   Content—Technical and practical aspects of fertilizer plant operation including trends in fertilizer industry development, new technologies for fertilizer production, basic engineering concepts in fertilizer production, and planning new fertilizer plants.

   Methodology—Observation of plant operations in selected countries; and formal presentations and discussions on problems of fertilizer production, plant operation, and performance improvement.

3. **Data Collection, Analysis, and Projections in Fertilizer Sector Studies**

   Location—IFDC; Nashville, Tennessee; and Washington, DC
   Number of Participants—24
   Countries Represented—16

   Target Audience—Mid- to senior-level personnel involved in

fertilizer-sector planning, research, production, and marketing functions.

Objectives—To build knowledge level and technical skills in methodologies for collecting and analyzing fertilizer-sector data and making fertilizer demand projections including data sources, sampling and data-analysis techniques involving the use of computers and other analytical methods.

Content—Examination of the data requirements, sources, gathering methodologies, analyses, and reporting in fertilizer planning, production, marketing, and use functions. Advantages and disadvantages of alternative methods for making fertilizer demand projections.

Methodology—Formal presentations and "hands-on" use of computers in data handling and analyses. Field trips to U.S. Federal agencies and private-sector organizations involved in fertilizer data gathering, analysis, and reporting.

4. **Advances in Fertilizer Technology, Marketing, and Use in the United States**

Location—IFDC and several U.S. locations

Number of Participants—18

Countries Represented—10

Target Audience—Senior-level managers of fertilizer manufacturing and marketing organizations. Senior-level government personnel involved in fertilizer-sector planning and operation.

Objectives—To present first-hand information on the latest developments in fertilizer production, marketing, and use in the United States through visits and discussions with technical experts and executives in public and private-sector fertilizer organizations.

Content—An overview of U.S. agriculture and supporting fertilizer systems. Examinations of the raw material base, fertilizer manufacturing processes and technologies, marketing and distribution systems, and research and extension systems.

Methodology—A series of cross-country visits for discussions with fertilizer producers, marketers, researchers, extension personnel, and control officials. Group discussions to share and evaluate ideas and concepts as they might apply to participants' country situations.

D. Ganapathy (foreground), an FMMTP participant, enters information on a microcomputer; he is assisted by Dr. R. T. Smith and R. S. Giroti.

5. **Development of Indigenous Phosphate Deposits Training Program**

Location—IFDC and Florida

Number of Participants—28

Countries Represented—20

Target Audience—Personnel with responsibilities for technical aspects of phosphate ore evaluation or exploitation and phosphate fertilizer production or use.

Objectives—To strengthen participants' skills in analyzing and developing solutions to problems related to developing phosphate resources for agricultural use. To examine phosphate development projects in Africa, Asia, and Latin America. To review phosphate research and production technologies.

Content—Emphasis on the multidisciplinary approach to phosphate resource development, including phosphate resource evaluation, rock characterization, mining and beneficiation process technologies, and economics. Evaluation of the agronomic and economic effectiveness of various phosphate fertilizers. Review of marketing and pricing of phosphate fertilizers.

Methodology—Classroom lectures and discussions supplemented by laboratory, pilot-plant, greenhouse, and field demonstrations. Field trip to Florida to observe phosphate mining, manufacturing, warehousing, and physical distribution operations and visits to agricultural experiment stations.

6. **USDA/IFDC/Auburn University Soil Testing and Soil Fertility Management**

Location—IFDC Headquarters

Number of Participants—18

Countries Represented—11

Target Audience—Agronomists/soil scientists engaged in soil testing and soil fertility research and management.

Field trips offer training participants a first-hand look at the fertilizer industry.

Objectives—To impart information on the latest advances in soil testing, analysis, and classification and fertility management. To discuss work underway at IFDC and other international agricultural research centers.

Content—Relationships between soil testing and soil classification. The practical aspects of applying soil tests to formulating fertilizer recommendations.

Methodology—Lectures and discussions supplemented by laboratory and greenhouse observations. Discussions with soil scientists at TVA's National Fertilizer Development Center.

7. **Fertilizer Marketing Management Training Program**

Location—IFDC and other U.S. locations

Number of Participants—23

Countries Represented—10

Target Audience—Middle- to senior-level fertilizer marketing managers with 3 or more years of experience in marketing management and plans to continue in similar work.

Objectives—To increase knowledge of the fertilizer industry and fertilizer marketing system To improve skills in identifying, analyzing, and resolving marketing-related problems. To develop ability in planning and implementing marketing system improvements and to improve communications and management skills.

Content—The structure and operation of the world fertilizer industry. The marketing function and organization and management of its individual components to promote expanded and more efficient use of fertilizer. Factors influencing marketing decisions, including supply/demand relationships, distribution systems, pricing, marketing margins, credit, etc. Modern marketing management concepts and management information systems including the use of microcomputers.

Methodology—Lectures, discussions, case studies, and "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, warehousing and distribution systems, research institutions, fertilizer dealers, and local farms.

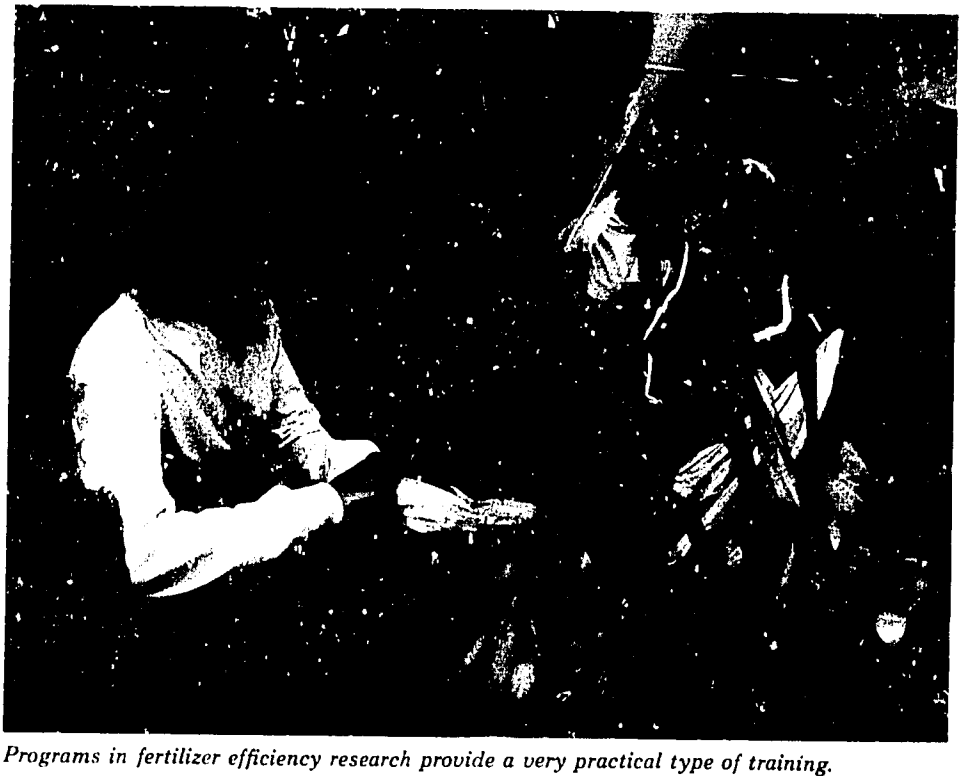
8. **Maintenance and Production Management Training Program**

Location—IFDC Headquarters and Louisiana

Number of Participants—27

Countries Represented—10

Target Audience—Fertilizer plant managers, maintenance and



Programs in fertilizer efficiency research provide a very practical type of training.

production superintendents, scheduling and procurement engineers and first-line production supervisors.

Objectives—To increase skills in organizing and managing maintenance and production functions. To impart a better understanding of the basic techniques used to identify, plan, schedule, and implement maintenance tasks to meet factory production goals.

Content—The theory and practice of plant production and maintenance management. Nitrogen plant operation and maintenance problems and procedures. Maintenance organization, documentation, planning and scheduling, stores procurement and inventory control, and human resource development.

Methodology—Classroom lectures and discussion supported by demonstrations of maintenance theories and operations at IFDC pilot plants, TVA demonstration-scale fertilizer plants and field s to commercial-scale fertilizer s. Workshop discussions of ammonia/urea production and maintenance problems featuring participant presentations on operations/maintenance problems at their plants.

9. **Caribbean Workshop on Fertilizer Technology and Marketing Systems**

Location—IFDC Headquarters
Number of Participants—14
Countries Represented—5
Target Audience—Senior-level public- and private-sector planners, producers, marketers, and market development specialists from five English-speaking countries of the Caribbean region.

Objectives—To provide a forum for identifying and discussing constraints to agricultural and fertilizer sector development in the Caribbean basin. To identify issues and formulate policy options for strengthening existing fertilizer research, extension, supply and marketing systems. To formulate guidelines for programs aimed at promoting the more rapid development and transfer of fertilizer supply and use technologies as a means of stimulating crop production.

Content—Presentations by participants of country profiles depicting the status of agriculture and the structure and operation of the fertilizer sectors in subject countries. IFDC staff presentations on fertilizer policy, research extension, marketing and supply problems, and solutions in developing countries. Identification of issues and formulation of policy options for expanding fertilizer use and enhancing fertilizer sector development in three main areas: the need for fertilizer, stimulating demand for fertilizer and assuming effective nutrient use, and supplying the needed fertilizers.

Methodology—Presentations and discussions at plenary sessions. The formation of working groups to define individual issues and recommend policy options for their resolution. General discussion and completion of working group recommendations. Visit to and discussion with TVA representatives on the impact of TVA's rural development programs on agricultural sector development in the Tennessee Valley. Field trips to local farm service center.

10. **Fertilizer Efficiency Research in the Tropics for the Asian Region**

Location—Puncak, Indonesia
Number of Participants—28
Countries Represented—6
Target Audience—Practicing agronomists/soil scientists responsible for field experimentation with at least 1 year of experience and a B.S. degree or equivalent in agronomy or related disciplines.

Objectives—To review advances in soil and crop science to increase understanding of factors influencing crop response to fertilizer. To improve capability to test and evaluate fertilizer materials and application methods. To present latest techniques for processing, analyzing, and interpreting results from field trials.

Content—Theoretical and practical aspects of fertilizer efficiency research emphasizing procedures for designing and conducting field trials with new and improved fertilizer materials and latest application techniques. Performing agronomic, statistical and economic analysis of test results.

Methodology—Course time about equally divided between classroom activities including lectures, discussions, and demonstrations, and field work featuring application of theory to practice. Participants design, plant, harvest, analyze, and report on field research experiments.

11. **Fertilizer Marketing Training Program for the Asian Region**

Location—Singapore
Number of Participants—22
Countries Represented—8
Target Audience—Middle-level or promotable junior-level fertilizer marketing managers having a minimum of 1 year's experience in fertilizer marketing management.

Objectives—To increase knowledge of the fertilizer industry and fertilizer marketing systems. To improve skills in analyzing marketing system performance and identifying and remedying constraints to effective performance. To develop capability to plan, organize, and implement improvements in marketing system operation.

Content—The marketing function and its elements including marketing planning, market research, identification of consumers and consumer needs, and demand forecasting. Physical distribution and warehousing programs. Factors affecting fertilizer use, supply/demand management, pricing and credit policies and practices. Managing the marketing function.

Methodology—Classroom lectures, discussions, and demonstrations featuring IFDC's

computer-assisted fertilizer marketing simulation exercise to provide "hands-on" experience in analyzing marketing systems and developing marketing strategies. Field trips to observe fertilizer plant and warehouse operation in Malaysia.

Individual Training

In addition to the group training programs identified above, IFDC also arranged and conducted thirteen individualized training programs for 134 participants from twelve countries (Table 9). Individualized training programs are specifically tailored to meet the unique needs of one or more individuals. Such training often takes place at IFDC but is also carried out at other U.S. and developing-country locations as is the case with in-country conducted nationally oriented training programs described later. Individualized training programs may range from several days to a year or longer and can cover virtually any aspect of fertilizer production, marketing, and use.

Evaluation

The improvement of currently offered training programs and the introduction of new training courses to better serve participants' needs are important considerations in IFDC program planning and development. Program evaluation is an ongoing and integral component of IFDC's overall training activities. Insights as to training program relevance and usefulness are gained through formal program evaluation forms completed by participants. The program evaluation questionnaire has itself been modified to improve the clarity of questions asked and ease of participant response as well as to make responses more adaptable to computer analysis. Although the organization of the program evaluation form may vary from program to program to reflect differences in program subject matter and conduct, the questions posed seek to determine participant reactions to the following four main areas: (a) technical aspects, (b) administrative aspects, (c) methodology, and (d) physical factors associated with program management.

Participant input has influenced IFDC training program thinking in respect to the types of programs required, subject matter emphasis, instructional methodology, and manner of program organization and conduct. Five new training programs were developed and presented in 1985 and three new program offerings were prepared for 1986. Greater emphasis is being placed on use of guest lecturers from developing countries, participant-oriented class exercises, and computer applications in fertilizer-sector operations. The areas of (1) economics of fertilizer production and use, (2) fertilizer use technology transfer, and (3) use of indigenous fertilizer materials are receiving greater attention.

Table 9. 1985 IFDC Individualized Training Programs

Program	Country	Number of Participants	Program Length (days)
Fertilizer Marketing Workshop	Bangladesh	26	7
Warehouse Management Workshops (3)	Bangladesh	77	6
Fertilizer Technology	Brazil	1	5
Crop Modelling Shortcourse	Indonesia	12	
Ammonium Nitrate Granulation	Israel	2	2
Mali Fertilizer Project	Mali	1	20
Development of Indigenous Phosphates	Mauritania	1	10
Soil Testing	Portugal	5	2
Phosphate Rock Beneficiation	People's Republic of China	5	2
Soil Testing	Swaziland	1	2
Phosphoric Acid Production	Tunisia	1	60
Phosphate Database	Togo	1	15
Bulk Blending	Uruguay	1	5
TOTAL		134	

Financial Report

Price Waterhouse

March 26, 1986

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, 1985 and 1984, 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

ASSETS

CURRENT FUND

	December 31, 1985	December 31, 1984
Cash	$ 88,055	$ 80,279
Certificates of deposit	217,939	1,457,604
Amounts receivable from donors (Notes 1 and 2)	3,701,339	3,587,681
Other accounts receivable	709,478	777,468
Advances to employees	68,695	81,548
Supplies inventory (Note 1)	140,223	152,270
Prepaid expenses	125,341	158,927
	$5,051,070	$6,295,777

NONCURRENT FUND

	December 31, 1985	December 31, 1984
Amounts receivable from donors (Notes 1 and 2) - restricted	$ 521,236	$1,065,000

BUILDINGS AND EQUIPMENT FUND (Note 1)

	December 31, 1985	December 31, 1984
Buildings	$5,734,995	$5,734,995
Equipment	4,782,296	4,811,804
Less - Accumulated depreciation	(4,623,116)	(4,025,067)
	$5,894,175	$6,521,732

LIABILITIES AND FUND BALANCES

CURRENT FUND

	December 31, 1985	December 31, 1984
Bank overdraft		$ 135,128
Accounts payable	$ 249,638	246,521
Accrued annual and sick leave	1,460,191	1,361,050
Deferred revenue (Notes 1 and 2)	3,443,997	3,587,681
Total liabilities and deferred revenue	5,153,826	5,330,380
Fund balance -		
Restricted	(95,509)	319,479
Unrestricted	(7,247)	645,918
	(102,756)	965,397
	$5,051,070	$6,295,777

NONCURRENT FUND

	December 31, 1985	December 31, 1984
Deferred revenue (Notes 1 and 2) - restricted	$ 521,236	$1,065,000

BUILDINGS AND EQUIPMENT FUND (Note 1)

	December 31, 1985	December 31, 1984
Contract retainage	$ 206	$ 412
Fund balance	5,893,969	6,521,320
	$5,894,175	$6,521,732

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1985 AND 1984

	Current Fund		Buildings and Equipment Fund		Total All Funds	
	1985	1984	1985	1984	1985	1984
Revenue:						
Grants (Note 2)	$5,713,652	$7,196,032			$5,713,652	$ 7,196,032
Recovered project costs	2,319,147	2,048,107			2,319,147	2,048,107
Other	97,489	143,689			97,489	143,689
Total revenue	8,130,288	9,387,828			8,130,288	9,387,828
Expenses:						
Research	4,513,619	4,907,007	$ 522,994	$ 496,183	5,036,613	5,403,190
Outreach	2,475,997	2,360,525	45,156	47,220	2,521,153	2,407,745
General and administrative	2,157,870	2,198,368	110,155	90,608	2,268,025	2,288,976
Total expenses	9,147,486	9,465,900	678,305	634,011	9,825,791	10,099,911
Excess (deficiency) of revenue over expenses	(1,017,198)	(78,072)	(678,305)	(634,011)	($1,695,503)	($ 712,083)
Other changes in fund balances:						
Equipment acquisitions from unrestricted funds	(50,954)	(635,728)	50,954	635,728		
Fund balances, beginning of period	965,396	1,679,197	6,521,320	6,519,603		
Fund balances, end of period	($ 102,756)	$ 965,397	$5,893,969	$6,521,320		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1985 AND 1984

	Research		Outreach		General and Administrative		Total Expenses	
	1985	1984	1985	1984	1985	1984	1985	1984
Personnel compensation (Note 3)	$2,485,879	$2,382,670	$1,249,547	$1,197,261	$1,090,733	$1,165,032	$ 4,826,159	$ 4,744,963
Personnel benefits (Note 3)	434,533	398,098	239,562	225,602	223,417	257,024	897,512	880,724
Travel and transportation	369,605	323,445	426,720	318,990	150,170	171,155	946,495	813,590
Occupancy	252,115	262,203	112,824	115,232	112,879	118,146	477,818	495,581
Telephone and telegraph	42,660	55,456	45,628	49,405	27,167	28,336	115,455	133,197
Rental of equipment	35,119	29,680	24,372	17,564	35,514	30,506	95,005	77,750
Contractual research and development	332,444	574,496	60,435	28,215	36,765		429,644	602,711
Other contractual services	184,933	270,632	187,068	183,200	159,444	192,314	531,445	646,146
Institute of International Education fee (Note 3)					104,826	90,116	104,826	90,116
Materials and supplies	318,531	568,758	100,941	204,271	188,055	124,955	607,527	897,984
Postage	25,967	16,385	12,983	8,193	12,983	8,193	51,933	32,771
Insurance	31,833	25,184	15,917	12,592	15,918	12,592	63,668	50,368
Miscellaneous	19,152	11,295		(1,157)	23,296	2,354	42,448	12,492
Total expenses before depreciation	4,532,771	4,918,302	2,475,997	2,359,368	2,181,167	2,200,723	9,189,935	9,478,393
Depreciation of buildings and equipment	503,842	484,888	45,156	48,378	86,858	88,253	635,856	621,519
Total expenses	$5,036,613	$5,403,190	$2,521,153	$2,407,746	$2,268,025	$2,288,976	$ 9,825,791	$10,099,912

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF CHANGES IN CASH AND CERTIFICATES OF DEPOSIT

	Years ended December 31,	
	1985	1984
Balances at beginning of year:		
Cash	$ 80,279	$ 416,636
Certificates of deposit	1,457,604	1,271,817
	$1,537,883	$1,688,453
Cash was provided by:-		
(Deficiency) of revenue over expenses	($1,695,503)	($ 712,083)
Charges not requiring (providing) an outlay of cash:		
Depreciation	635,856	621,519
(Gain) loss on disposal of equipment	42,448	12,492
Increase in accrued annual and sick leave	99,141	139,104
Cash provided from operations	(918,058)	61,032
Proceeds from sale of equipment	2,230	4,471
Net decrease in other accounts receivable	67,990	355,737
Net decrease in advances to employees	12,853	
Net decrease in supplies inventory	12,047	
Net decrease in prepaid expenses	33,586	28,725
Net increase in bank overdraft		135,128
Net increase in accounts payable	3,117	
	(786,235)	585,093
Cash was used for:		
Purchase of buildings and equipment	52,978	640,219
Net increase in current amounts receivable from donors	113,658	
Net increase in advances to employees		19,123
Net increase in supplies inventory		7,493
Net decrease in bank overdraft	135,128	
Net decrease in deferred revenue (current fund)	143,684	
Net decrease in contract retainages	206	68,828
	445,654	735,663
Net increase (decrease) in cash	($1,231,889)	($ 150,570)
Balances at end of year:		
Cash	$ 88,055	$ 80,279
Certificates of deposit	217,939	1,457,604
	$ 305,994	$1,537,883

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,			
	1985		1984	
	Restricted	Unrestricted	Restricted	Unrestricted
Grants received -				
United States Agency for International Development (AID)	$ 199,718	$4,000,000	$ 250,000	$4,000,000
International Fund for Agricultural Development (IFAD)			1,100,000	
Australian Development Assistance Bureau (ADAB)		589,430	147,112	188,560
International Development Research Centre (IDRC)	192,056		814,742	
Ford Foundation				76,000
Israel Chemical Company		45,000		
	391,774	4,634,430	2,311,854	4,264,560
Amounts deferred during prior year	2,892,110	1,760,571	2,917,299	2,355,000
	3,283,884	6,395,001	5,229,153	6,619,560
Less - Amounts deferred to future periods	1,991,975	1,973,258	2,892,110	1,760,571
Revenue recognized in current period	$1,291,909	4,421,743	$2,337,043	4,858,989
		1,291,909		2,337,043
Total restricted and unrestricted		$5,713,652		$7,196,032

The unrestricted grants from AID provided funds of $4,000,000 during each of the fiscal years ending June 30, 1986 and 1985. The unrestricted ADAB grants in 1985 and 1984 were gifts of funds recognized as revenue in the year received. The 1984 restricted ADAB grant represents additional funding for a project in Southeast Asia.

Restricted grants from AID, IFAD and IDRC were restricted by the grantor as to specific projects and geographic regions. The IFAD grant, $1,100,000 in 1984, provided funds for the final year of a three year IFDC research program in Africa. The termination date of the grant was extended into 1985 to allow for additional project and workshop expenditures. The IDRC grants in 1985 and 1984 provided funds for research projects in Latin America, to be completed November 30, 1986, West Africa, originally to have been completed November 30, 1985 but extended into 1986 by oral agreement with IDRC, and a second project in West Africa, to be completed June 30, 1987. Any grant funds not expended at the grant expiration date will revert to the grantor.

Receivables from donors at December 31, 1985 and 1984 are summarized as follows:

	December 31,			
	1985		1984	
	Restricted	Unrestricted	Restricted	Unrestricted
AID	$ 271,466	$2,185,000	$ 222,829	$1,692,171
UNDP	1,065,000		1,775,000	
IFAD			200,000	
IDRC	655,509		694,281	
Ford Foundation		45,600		68,400
	1,991,975	2,230,600	2,892,110	1,760,571
Less - noncurrent portion	(521,236)		(1,065,000)	
	$1,470,739	2,230,600	$1,827,110	1,760,571
		1,470,739		1,827,110
Total restricted and unrestricted		$3,701,339		$3,587,681

The United Nations Development Programme (UNDP) grant provided funds for various research and outreach projects for grant periods of more than one year. The UNDP grant expires in 1987. Funds relating to this grant receivable not budgeted for expenditure in 1986 and 1985 are classified as noncurrent at December 31, 1985 and 1984, respectively.

NOTE 3 - INSTITUTE OF INTERNATIONAL EDUCATION:

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

IFDC Board of Directors

(as of December 31, 1985)

Chairman

Dr. John A. Hannah
President Emeritus
Michigan State University
U.S.A.

Dr. Anton Amberger
Professor
Institute of Plant Nutrition
University of Munich
Federal Republic of Germany

Dr. Fernando Cardoso
President
MANAH
Brazil

Dr. Ola Heide
Rector
Agricultural University of Norway
Norway

Dr. David Hopper
The World Bank
U.S.A.

Dr. Amir Muhammed
Chairman
Pakistan Agricultural
Research Council
Pakistan

Dr. Bukar Shaib
Minister of Agriculture
Nigeria

Mr. Adolfo Sisto
General Manager
Industrial Operations
FERTIMEX
Mexico

Dr. Entol Soeparman
Director
Research and Development
P.T. PUSRI
Indonesia

Dr. Robert E. Wagner
President
Potash and Phosphate Institute
U.S.A.

Mr. William F. Willis
General Manager
TVA
U.S.A.

Mr. Miguel Zosa
President
PHILPHOS
The Philippines

Ex Officio Member

Dr. Donald L. McCune
Managing Director
IFDC

Ex Officio Member

Marjorie R. Brashier
Administrative Director
IFDC

Staff

Office of the Managing Director

Donald L. McCune, Managing Director
Paul J. Stangel, Deputy Managing Director
Marjorie R. Brashier, Administrative Director
John H. Allgood, Personnel Officer
Kaye F. Barker, Accountant
Jacqueline A. Berrens, Purchasing Clerk
Betty F. Canerday, Mail Clerk
Glenda Carter, Accounting Clerk
Linda B. Cornatzer, Word Processing Specialist
Kathy H. Creamer, Graphic Designer
C. David Edwards, Budget Officer
Brenda S. Elmore, Word Processing Specialist
Mary S. Evers, Part-Time Librarian
Ernest D. Frederick, Technical Editor
Janice C. Gautney, Word Processing Specialist
Jane L. Goss, Word Processing Specialist
Alicia K. Hall, Word Processing Specialist
Amber N. Hammock, Correspondence Secretary
Travis P. Hignett, Special Consultant to the Managing Director
Vickie J. Hollandsworth, Word Processing Specialist
W. Diane Kasmeier, Assistant Purchasing Agent
James M. Kelly, Purchasing Agent
Julie G. Martin, Student Worker
Terry L. McGee, Graphic Artist/Media Technician
Betty Jo Merritt, Librarian
Jean G. Meyer, Mail Clerk
Dennis T. O'Brien, Economist*
Brian Palmer, Liaison Scientist
Brenda G. Peden, Accounting Clerk
Faye Predmore, Switchboard Operator
Jean S. Riley, Assistant Librarian
Elizabeth N. Roth, Editor
Flora M. Rudolph, Technical Illustrator
Debra R. Rutland, Executive Secretary
Patricia F. Sandlin, Word Processing Specialist
Dorothy B. Sentz, File Clerk
Debra S. Shedd, General Accountant
Parminder Singh, Visitor Relations Officer*
Carol F. Slaton, Word Processing Specialist
Janice D. Smith, Secretary*
James C. Starkey, Draftsman
Marie R. Stribling, Coordinator, Word Processing Center
Joy M. Thompson, Accounting Clerk
Marie K. Thompson, Communications Supervisor
Donna W. Venable, Word Processing Specialist
Gwendolyn A. Watts, File Clerk
Joel G. White, Draftsman*
Tommy L. Wright, Photographer/Media Technician
Lynda F. Young, Assistant Editor

Agro-Economic Division

Paul L.G. Vlek, Director
Mary C. Irons, Administrative Secretary
Jacqueline Ashby, Sociologist
Ernest R. Austin, Instrumentation Specialist
Carlos A. Baanante, Economist
Andre M. Bationo, Soil Scientist
Karen S. Billingham, Laboratory Supervisor
Roland J. Buresh, Soil Scientist
Bernard H. Byrnes, Research Associate
Michael F. Carter, Research Associate/Greenhouse Supervisor
S. H. Chien, Soil Chemist
C. Bruce Christianson, Soil Scientist
John T. Colagross, Electronics Specialist
Karen Dvorak, Postdoctoral Fellow
Michael W. Elliott, Research Assistant*
Ronnie L. Faires, Greenhouse Technician
C. Durant Frederick, Greenhouse Technician
Dennis K. Friesen, Soil Scientist
Douglas C. Godwin, Agronomist/Systems Modeler
Scott E. Guggenheim, Postdoctoral Fellow
Bryan W. Hamilton, Chemical Laboratory Analyst
Lawrence L. Hammond, Soil Scientist
Karl Harmsen, Soil Scientist
Deborah T. Hellums, Research Associate
Julio Henao, Biometrician
Vance E. Henry, Greenhouse Technician*
Susan C. Highfield, Research Assistant
Leella S. Holt, Laboratory Supervisor
Chong-Woon Hong, Soil Scientist
Rebecca Hufstedler, Assistant Programmer/Data Processor*
Norbert Kang, Student Worker*
Jagdish C. Katyal, Visiting Scientist
L. Alfredo Leon, Soil Scientist
Dian-Qing Lu, Visiting Scientist*
Charles T. McCafferty, Greenhouse Technician
Lynne Malone, Chemical Laboratory Analyst
Kathryn G. Matthews, Chemical Laboratory Analyst
R. G. Menon, Visiting Scientist*
Mark A. Mitchell, Chemistry Co-op Student*
Uzo Mokwunye, Soil Scientist
Mohamed Abdel Monem, Visiting Scientist*
Mohinder S. Mudahar, Economist
Spider K. Mughogho, Soil Scientist*
Martin K. Painter, Chemistry Co-op Student
Nancy A. Potter, Correspondence Secretary
Leigh A. Putnam, Chemical Laboratory Analyst

Marilou del Rosario, Chemical Laboratory Analyst
Lea Anne L. Schultz, Laboratory Technician
Surjit Sidhu, Economist
John P. Skipworth, Chemistry Co-op Student
Diane Sompongse, Research Associate*
M. Patricia Stowe, Correspondence Secretary
John M. Stumpe, Research Associate
A. Ray Till, Visiting Scientist*
Bobi R. Wilson, Chemical Laboratory Analyst*
Leif J. Youngdahl, Crop Physiologist
Cynthia B. Zickos, Computer Operator-Programmer

Fertilizer Technology Division

Owen W. Livingston, Director
Delilah A. Forsyth, Administrative Secretary
Ibezim J. Anazia, Minerals Engineer*
Cathy W. Anderson, Correspondence Secretary
Andrea L. Arthur, Chemical Laboratory Analyst*
Anthony Bailey, Student Worker
Billy W. Biggers, Jr., Analytical Chemist
Bobby W. Biggers, Chemist
George W. Bolds, III, Pilot-Plant Operations Coordinator
Robert C. Bosbeers, Engineering Research Technician
Terry L. Buchanan, Technical Aide
Virlyn L. Bulger, Technical Aide*
William R. Clayton, Research Chemist
Jerry R. Clemmons, Chemist
Dwight E. Cline, Technical Aide*
Doyce E. Couch, Assistant Maintenance Coordinator
Karen S. Couch, Chemist*
Branson E. Downing, Safety Engineer*
Nathan A. Engle, Maintenance Technician
Thomas E. Evers, Technical Aide
Frances H. Glover, Correspondence Secretary
Marshall E. Goode, Technical Aide
Celia J. Guinn, Chemical Laboratory Analyst
Brenda A. Hamilton, Chemist
Michael D. Hellums, Maintenance Technician
Gary L. Hines, General Helper
Robert G. Howard, Chemist
Angela F. James, Chemist
Vanessa E. Keel, Chemical Laboratory Analyst
Raymond H. Kluesner, Student Worker
Talaat A.B. Lawendy, Minerals Engineer
Jose R. Lazo de la Vega, Special Project Engineer
Alan E. Madewell, Engineering Co-op Student*
Benjamin C. Malone, Engineering Research Technician
Guerry H. McClellan, Research Coordinator
Ramiro Medina, Enzyme Biochemist*
Charlie M. Murner, Maintenance Technician*
T. Alan Nix, Assistant Pilot-Plant Operations Coordinator
G. Erick Peters, Chemist
Jorge R. Polo, Deputy Engineering Coordinator
H. Dale Richards, Warehouse Technician
Johnnie W. Riley, Maintenance Coordinator
James A. Robertson, Technical Aide*
Amitava H. Roy, Special Project Engineer
Irwan T. Rusli, Special Project Engineer
David W. Rutland, Physical Properties Specialist
Narayan K. Savant, Soil Chemist (Nitrogen)
James J. Schultz, Engineering Coordinator
James H. Stough, Laboratory Assistant*
Michael O. Thompson, Technical Aide
Steven J. Van Kauwenbergh, Mineralogist/Petrographer
Paul H. Whitlock, Maintenance Technician**
Marilyn R. Williams, Chemist
Terry C. Woodis, Consultant
David B. Wright, Engineering Research Technician
David P. Wright, Chemist

Outreach Division

Dennis H. Parish, Director
Deborah B. King, Administrative Secretary
Daris H. Belew, Correspondence Secretary
Robert D. Benton, Distribution Consultant*
William T. Brooks, Engineering Consultant
Yao H. Chuang, Market Development Economist
W. Edward Clayton, Transportation/Distribution Specialist
Ray B. Diamond, Research/Training Consultant
Roswell C. Doremus, Engineering Consultant
Stephen J. Dunbar, Instrument Engineer
M. Terry Frederick, Chemical Engineer
Evelyn Freeman, Secretary
Ram S. Giroti, Associate Training Coordinator
Gene T. Harris, Economist
Regina S. Harris, Marketing Research Assistant
John M. Hill, Marketing Specialist
Dennis E. Hyde, Maintenance Engineer
Edwin C. Kapusta, Regional Coordinator—Asia
Nam D. Le, Chemical Engineer
Vincent E. Leon, Engineering Consultant
A. Frank Little, Industrial Project Analyst*
Adolfo Martinez, Agricultural Economist
Ann H. Mock, Correspondence Secretary
Kenneth L. Moots, Marketing Consultant
Olabisi Ogunfowora, Visiting Scientist
Pierre M. Rosseau, Tropical Agronomist
Yosef Dan Shahar, Economist
Victor L. Sheldon, Marketing Specialist
Glenda F. Smallwood, Marketing Research Assistant
Roy Smaltz, Engineer
Robert T. Smith, Training Specialist
Linda W. Trousdale, Marketing Research Assistant
Jimmy Waddell, Training Aide
Lewis B. Williams, Regional Coordinator—Africa

*Left in 1985.
**Retired in 1985.

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

ISSN-0748-5875

Edited by Marie K. Thompson/Draft Typing, Donna W. Venable/Typesetting, Jane L. Goss and Patricia F. Sandlin/Watercolors, Flora Rudolph/Graphic Illustrations, James C. Starkey/Design, Layout, and Cover, Terry L. McGee and James C. Starkey.
Photo Credits. Charles Butler, former Peace Corps/Kenya photographer, p. ii (bottom), p. 34; Dr. Bruce Christianson, cover (center), p. iii (bottom); Dr. W. E. Clayton, p. 28; Dr. Dennis Friesen, p. 19; R. S. Giroti, p. 40; Dr. J. A. Ashby, p. 15; Pierre Rosseau, p. iii (top), p. 31; Dr. N. K. Savant, p. 2; Ron Shaw, USAID/Yaounde, Cameroon Cinematographer, cover (left), p. ii (top), Dr. V. L. Sheldon, cover (right), p. 35; Lewis B. Williams, p. iv (top); and Tommy L. Wright, pp. 3, 4, 11, 12, 20, 26, 39.

IFDC Profile

Origin and Mission—In 1974 the U.S. Secretary of State in a speech before the General Assembly of the United Nations urged the establishment of an international fertilizer center. This center would focus on the development of appropriate fertilizer technology and related knowledge to increase food production in the developing countries, especially those in the tropics and subtropics.

The center that evolved is today known as the International Fertilizer Development Center (IFDC). On October 7, 1974, IFDC was officially registered in the State of Alabama as a private, nonprofit corporation. On March 14, 1977, IFDC was designated as a nonprofit, public international organization.

Funding—Planning funds to establish IFDC came from the United States Agency for International Development (USAID) and the International Development Research Centre (IDRC) of Canada. In addition to the continuing support of these two organizations, funds for training, technical assistance, and research and development come from a wide range of national and international agencies.

Location—IFDC is located in Muscle Shoals, Alabama. Its proximity to the Tennessee Valley Authority's (TVA) National Fertilizer Development Center (NFDC) facilitates a sharing of research information and a comprehensive fertilizer library.

Board—Program directions are shaped by a Board of Directors that is fully international and was established in accordance with standards set by the Consultative Group on International Agricultural Research (CGIAR). The members of the Board bring together a wide range of fertilizer expertise.

Staff—The IFDC staff of 165, recruited from 17 countries, is both internationally and technically diverse with almost half of this number being chemical engineers, chemists, economists, agronomists, geologists, soil scientists, and sociologists. IFDC is able to conduct unique fertilizer research and development because of three complementary factors: (1) the multidisciplinary structure of the task teams used for research planning; (2) the ability to produce and test experimental fertilizers in laboratories, pilot plants, and greenhouses; and (3) linkages with research institutions around the world.

Framework—IFDC has three divisions—Agro-Economic, Fertilizer Technology, and Outreach. The Office of the Managing Director is the administrative section of IFDC. The Agro-Economic and Fertilizer Technology Divisions are research oriented and focus on the development of products and practices to solve immediate and long-term problems. The Outreach Division is responsible for training information dissemination, identification of problems of regional and global importance, and national field programs of an adaptive research nature.

Facilities—The three divisions are supported by facilities that include laboratories; greenhouses; growth chambers; specialized instruments essential for laboratory research; bench-scale and pilot plant units used in studies such as beneficiation of ores, acidulation, and granulation of fertilizers; and audiovisual, communications, and word processing centers capable of disseminating information through various media.

Linkages—To help carry out its mission, IFDC cooperates with many international, regional, and national institutions. IFDC has 15 staff specialists posted at a number of these institutions. Technology developed by IFDC scientists and engineers is tested under a wide range of conditions before its applicability is established for specific areas.