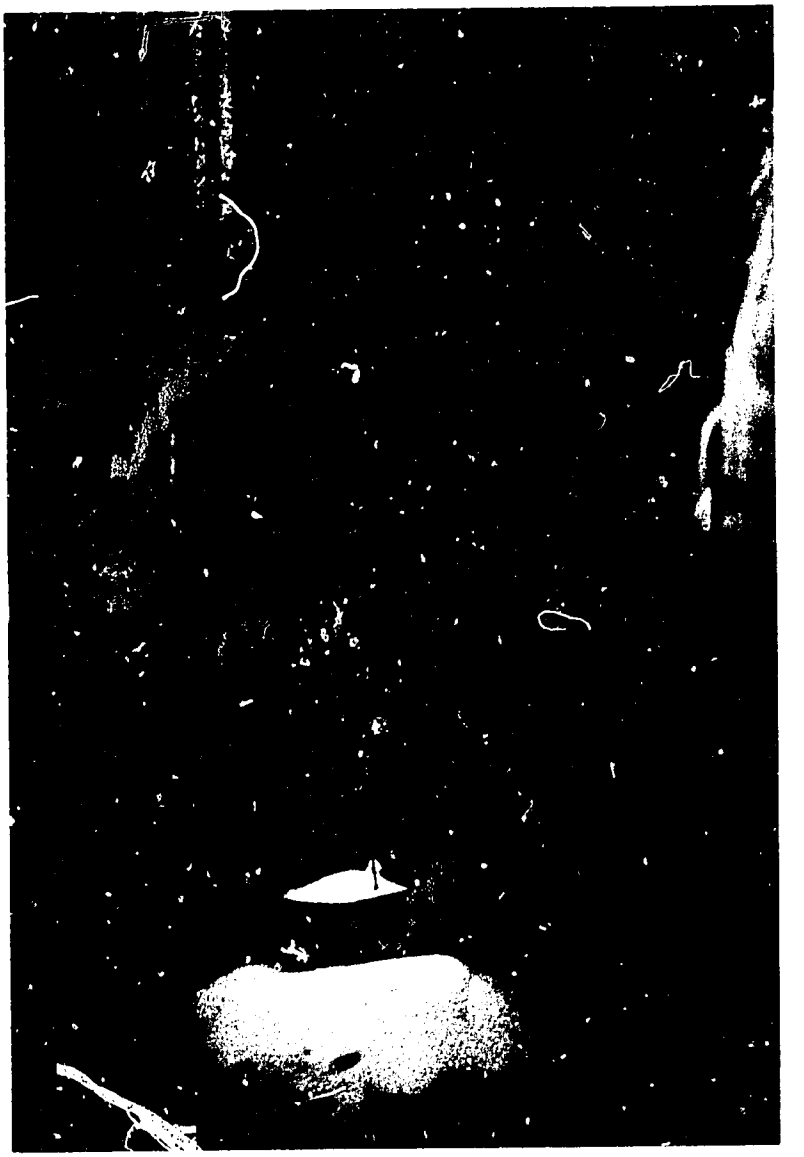
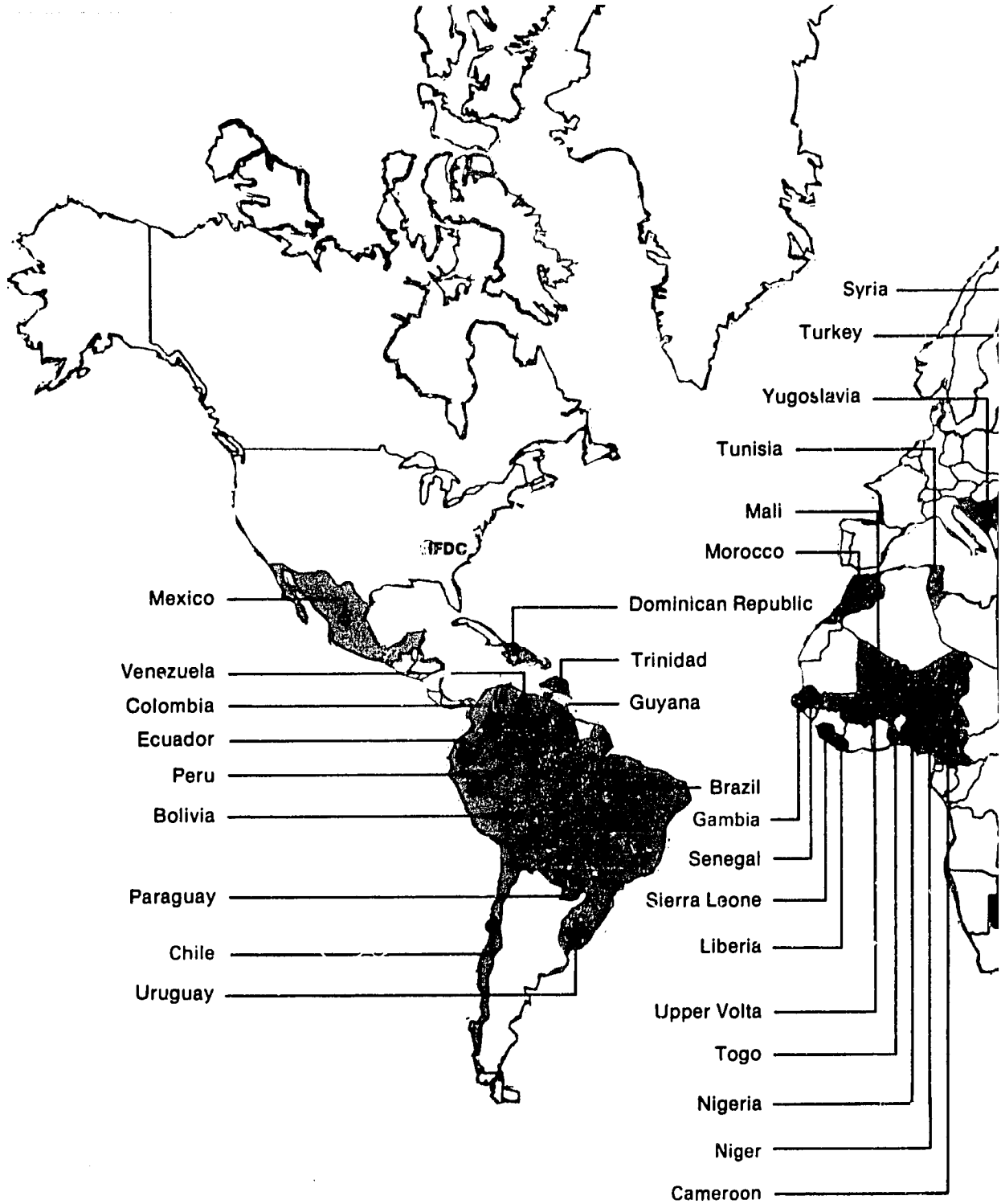
International Fertilizer Development Center
Annual Report 1983

"Through research, national programs, technical assistance, and training, IFDC furthers its mission of 'increasing food production of the developing countries through the development of improved fertilizers and fertilizer practices.' As depicted on the cover and throughout the four sections of this volume, IFDC's work is conducted in our Headquarters laboratories, greenhouses, and pilot plant and in fields of developing countries in the tropics and subtropics. As represented by the people pictured on the cover and on the four division pages, the areas of emphasis for our work are Africa, Asia, and Latin America."

Dr. Donald L. McCune
Managing Director
IFDC



A Bangladesh fertilizer dealer sells urea.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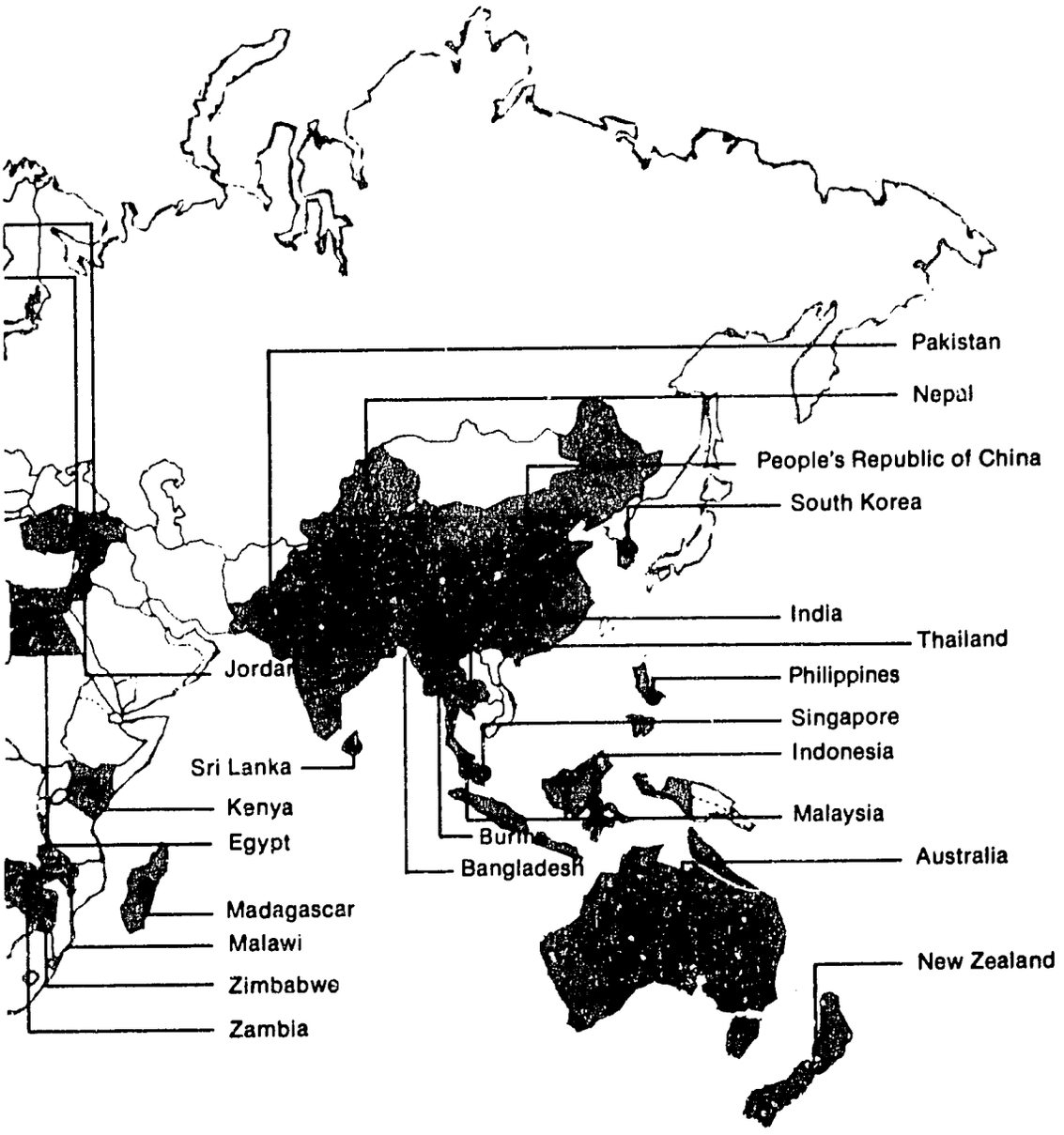
IFDC
In-Country Involvement



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 178, recruited from 20 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 17 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.

For HDC the promise of tomorrow lies with young people like these from Nicosia.

Report From the Management

The Year in Retrospect —

Developing nations realize that they must increase their capability of producing food in order to feed their growing populations. They want to use their own resources, wherever possible, to feed their people. Fertilizer is a key input in helping these countries achieve this goal. During 1983 IFDC furthered its efforts toward developing more effective fertilizers to help produce more food for the world's people.

Because urea is the main nitrogen fertilizer used worldwide, its efficient use received priority during 1983. IFDC continued its evaluation of methods for modifying urea to improve its properties.

During 1983 IFDC's researchers expanded their study of the efficient use of indigenous phosphate rock; phosphate field research was conducted in Latin America, Africa, and Asia. During the past year IFDC conducted special studies on the use of indigenous phosphate rock from India, Malaysia, Chile, Niger, Senegal, Thailand, Uganda, the Philippines, and Jordan.

IFDC's sulfur research during 1983 focused on reactions of potential sources of sulfur when applied to soils under both flooded and upland conditions.

During 1983 IFDC, with assistance from the International Potash Institute and the Potash and Phosphate Institute, conducted a major study to analyze the role of potassium fertilizers in tropical agriculture.

Two major studies involving economics research included a fertilizer equity study focusing on Bangladesh and an intensive study of fertilizer use in India.

IFDC's national programs, established in Bangladesh, Indonesia, and Mali, continued to expand. During 1983 the program in Mali, designed to help that country find the best possible use of its indigenous phosphate rock, branched out onto farmers' fields for more intensive evaluations.

Through technical assistance projects, IFDC continued to transfer its research and development innovations to developing countries.

In 1983 IFDC administered eleven group training programs for 292 individuals from 38 different countries. New programs were offered covering topics, such as data collection and analysis, soil testing, and fertility management.

With a multidisciplinary staff to study problems of fertilizer production, marketing, and use, IFDC is helping to increase food production in developing countries through improved fertilizers and fertilization practices.

The Promise of Tomorrow —

IFDC believes that for developing countries the promise of tomorrow lies with the people themselves. The Center is dedicated to helping them help themselves and continues to look for ways of establishing a greater presence in these regions.

Donald L. McCune
Managing Director

Paul J. Stangel
Deputy Managing Director

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Indian workers manually unload urea fertilizer.

"During the past 2 years I've been involved in research that studies nitrogen loss mechanisms. A significant amount of applied fertilizer nitrogen is being lost in a gaseous form. If we can come up with a way to reduce these losses in the fields, this will help farmers tremendously."

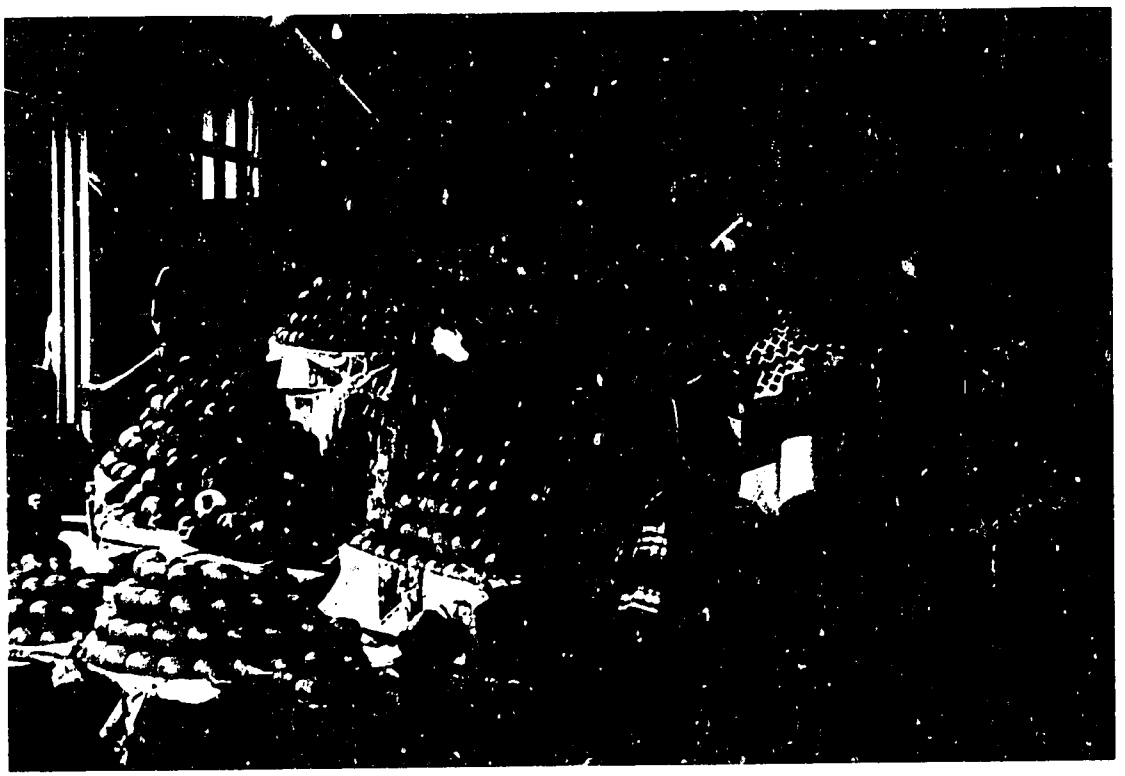
Dr. Diane Sompongse, Postdoctoral Fellow
Agro-Economic Division, IFDC

Research Program

The fertilizer research program of IFDC involves experimental product and process development in laboratories and pilot plants and agronomic evaluations conducted in laboratories and greenhouses at Headquarters. Promising products are field tested by IFDC staff stationed in developing countries. They are also tested through cooperative agreements with various international organizations and national institutions and by regional agronomic evaluation networks. If the field results promise a reasonable return on investment for fertilizer, the technology may be transferred to farmers' fields in developing countries. Depending on the results, the technology may then be implemented on larger scale. Thus, the research program encompasses development of production and process technology as well as agronomic and economic evaluation.

Research remains sharply focused on two major objectives: (1) improving nutrient use efficiency and (2) maximizing use of indigenous resources in developing countries. The overall program is balanced to study relevant problems of the developing countries of Asia, Africa, and Latin America. Because urea is the main nitrogen fertilizer used worldwide, its efficient use as a single product or in combination with the other primary nutrients, phosphorus and potassium, is receiving priority. IFDC is evaluating methods for modifying urea to improve its chemical and physical properties. During 1983 IFDC researchers continued studies on the efficient use of indigenous phosphate rock to prepare fertilizers through various processing routes. They are making comparisons of efficiencies of sulfur sources alone and with other nutrients. The combination of all nutrients, including micronutrients, into homogeneous granules acceptable for humid tropical conditions presents a special challenge.

With a multidisciplinary staff to study problems of fertilizer production, marketing and use, IFDC is promoting increased food production through fertilizer use.



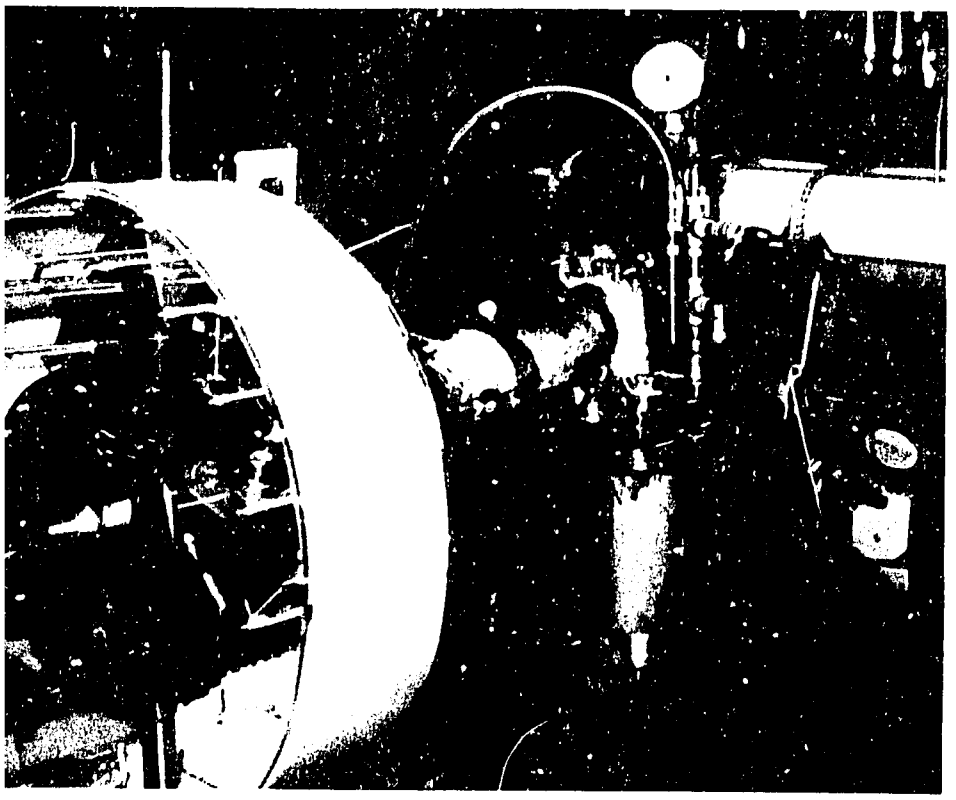
The ultimate goal of IFDC's research program is increased food production. Pictured here, Bangladesh vendors sell the fruits of their labor.

Nitrogen Research

Nitrogen fertilizer used in developing countries is primarily solid prills or granules that are manually applied to the soil surface. Under certain soil-cropping conditions, some of the nitrogen is not being used efficiently by the crops. IFDC programs seek more information on the magnitude and mechanisms of nitrogen losses in order to develop techniques for improved efficiency. Most of the nitrogen fertilizers are under study, but urea is receiving the most attention.

For rice in Asia two routes for urea modification have demonstrated increased rice yields in several locations: coated granular urea having a controlled dissolution rate for surface application and large urea particles for deep placement. Both techniques demonstrate improved agronomic performance. Unfortunately, commercial development of the two products has been hindered by the cost of the coated product and the intensive labor required for deep placement of the large particles. IFDC is continuing to search for ways to lower these costs. Farmers prefer to surface apply nitrogen fertilizer; this method requires no change in crop planting and fertilizer application methods. Products such as coated urea, urea combined with inhibitors, and urea modified by chemical reaction can be used in this way. Large particles of urea alone or with other nutrients can be deep placed by hand or machine. IFDC is studying the agronomic and economic factors affecting the use of these various types of modified urea fertilizers.

This laboratory rotary-drum coating unit is used for coating urea with rubber latex.



Materials for Improved Efficiency

Coated Urea Fertilizer

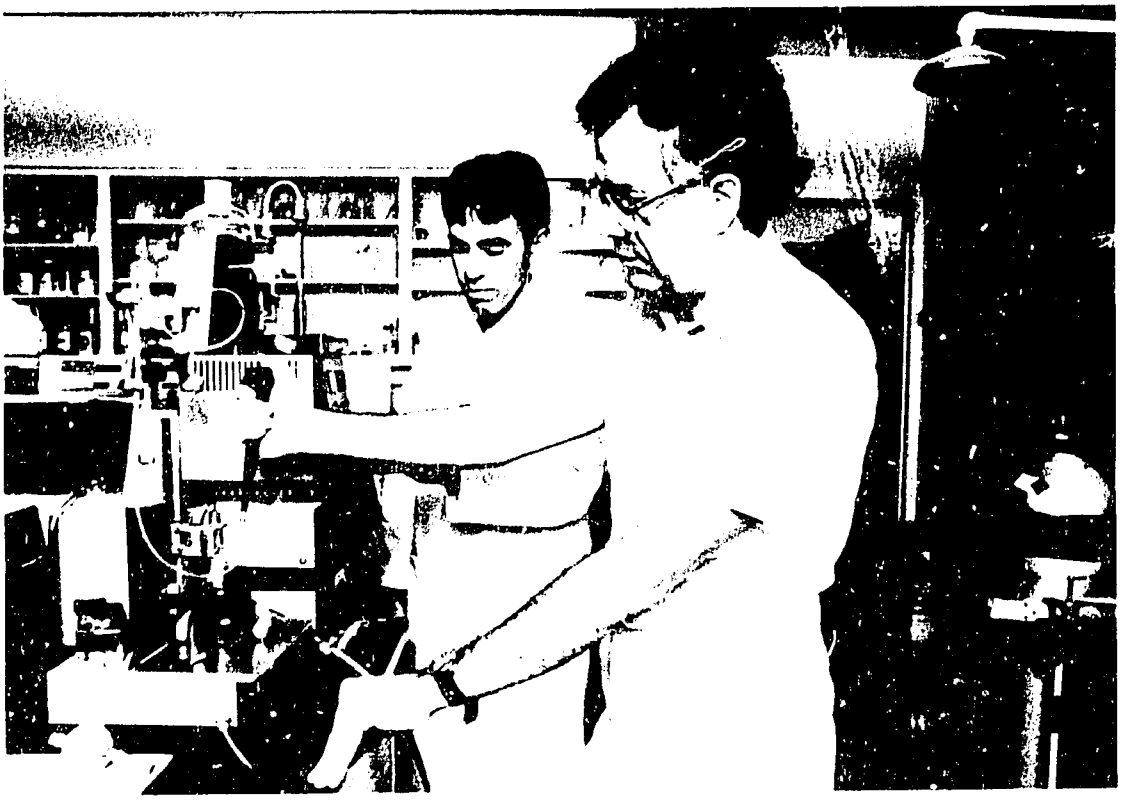
Equipment modifications have improved IFDC's capabilities in applying coatings. Two application methods (fluid bed and rotary drum) are available for batch laboratory-scale coating using melts (molten wax or sulfur), solutions, or emulsions (rubber latex). IFDC prepared rubber latex-coated urea under a wide range of coating conditions on two substrate particle sizes by the two processes. The data were used to develop conceptual designs for commercial production; these preliminary findings must be confirmed in continuous pilot-plant tests.

A coated fertilizer may also have improved physical properties. Rubber-coated granular urea was less subject to degradation than uncoated urea. In addition, it may be blended with granular superphosphate for storage, which is not recommended for uncoated urea. IFDC has considerable experience in evaluating the chemical and physical properties of coated urea fertilizer.

Cost estimates indicate that raw materials must be reduced by minimizing the coating weight. Energy efficiency and process simplicity must be achieved for successful adaptation of the processes to developing countries. Laboratory studies have established the groundwork for achieving this.

Chemically Modified Urea

Work was continued on the incorporation of a urease inhibitor, phenylphosphorodiamidate (PPD), into urea and an agronomic evaluation of the mixture. Mixing the inhibitor with urea retards the hydrolysis to ammonia and carbon



Dr. Erick Peters (left), IFDC Chemist, and Dr. Ramiro Medina, Visiting Scientist, use this pH-stat system to evaluate urease inhibitors for urea.

dioxide and improves nitrogen efficiency. Some drawbacks are the high cost of PPD and its instability. Therefore, IFDC initiated a program in late 1982 to better understand the mechanism of urease inhibition using a rapid laboratory method to measure the relative effectiveness of compounds added to urea.

Urea containing an inhibitor is intended for surface application in the form of conventional-size granules. IFDC has used the compaction granulation method to prepare small test quantities for agronomic evaluation. This method of preparation may also be practical for commercial-scale production. Other researchers are studying the addition of PPD to urea melt in a simulated prilling or granulation process.

Urea Particle-Size Modification

Increasing the particle size of urea makes it easier to deep place the fertilizer into rice paddies by hand or machine. Experimental quantities of large urea particles--called "supergranules"—can be made by melt granulation or briquetting. IFDC is using the briquetting process as described in an IFDC technical bulletin, entitled *Briquetting: Alternative Process for Urea Supergranules*. A technical/economic comparison is made of supergranule production by briquetting and granulation under various assumptions.

Synthesis of ^{15}N Urea

Since IFDC is using a large amount of labeled ^{15}N urea for agronomic studies, a synthesis method was developed to produce labeled urea at Headquarters. The synthesis is based on reaction of ^{15}N ammonia with phenyl carbonate to yield urea and phenol with 95% or higher conversion. Equipment was assembled for the laboratory preparation.

Synthesis of Ureaform Slow-Release Fertilizers

During 1983 IFDC developed a new technique for the synthesis of ureaform fertilizers. The new technique involves reaction of molten urea with a paraformaldehyde polymer to produce ureaforms. This technique offers numerous advantages over existing ureaform preparation methods in which urea-formaldehyde solutions are made, subjected to a series of pH adjustments, and then evaporated to dryness.

Ureaforms prepared by the technique have been analyzed extensively by high-pressure liquid chromatography and are currently undergoing greenhouse trials on both flooded and upland conditions. They represent a source of controlled-release nitrogen.

Characterization of Metal Salt-Urea Complexes

IFDC prepared several metal salt-urea complexes from the chloride, nitrate, and sulfate salts of aluminum, copper, iron, manganese, and zinc to study their effect on urea hydrolysis and/or ammonia volatilization in soil. Chemical analyses showed that the complexes had the expected metal salt-urea ratios and that all water of hydration originally in the metal salt had been removed. Infrared spectra of the complexes indicated that the urea molecules were coordinated to the metals through the oxygen atom. The x-ray powder diffraction patterns of the aluminum, iron, and manganese complexes showed the presence of a new coordination complex and the absence of urea or metal salt species. Thermal decomposition of the urea complexes—aluminum urea nitrate, ferrous urea nitrate, and manganese urea chloride—was studied in air and argon by simultaneously recording the thermogravimetric, differential thermal gravimetric, and differential thermal analysis curves. The metal oxides formed by the decompositions were identified by x-ray powder diffraction, and decomposition stoichiometries were proposed. The nitrate complexes decomposed in a single-stage process, whereas the chloride complex decomposed in a multistep process.

Preparation of Experimental Materials

For agronomic research a number of experimental products were made. Some examples are: urea coated with rice bran wax, sulfur-coated urea (SCU), urea coated onto urea phosphate, calcium-ammonium nitrate (CAN), urea plus calcium cyanamide, urea mixed with inhibitors (N-Serve, PPD, dicyandiamide [DCD]), ammonium chloride plus N-Serve, and urea phosphate. Some of the products were furnished as powders; others were sized by tableting or briquetting. Some were labeled with ^{15}N.

Lowland Nitrogen Program

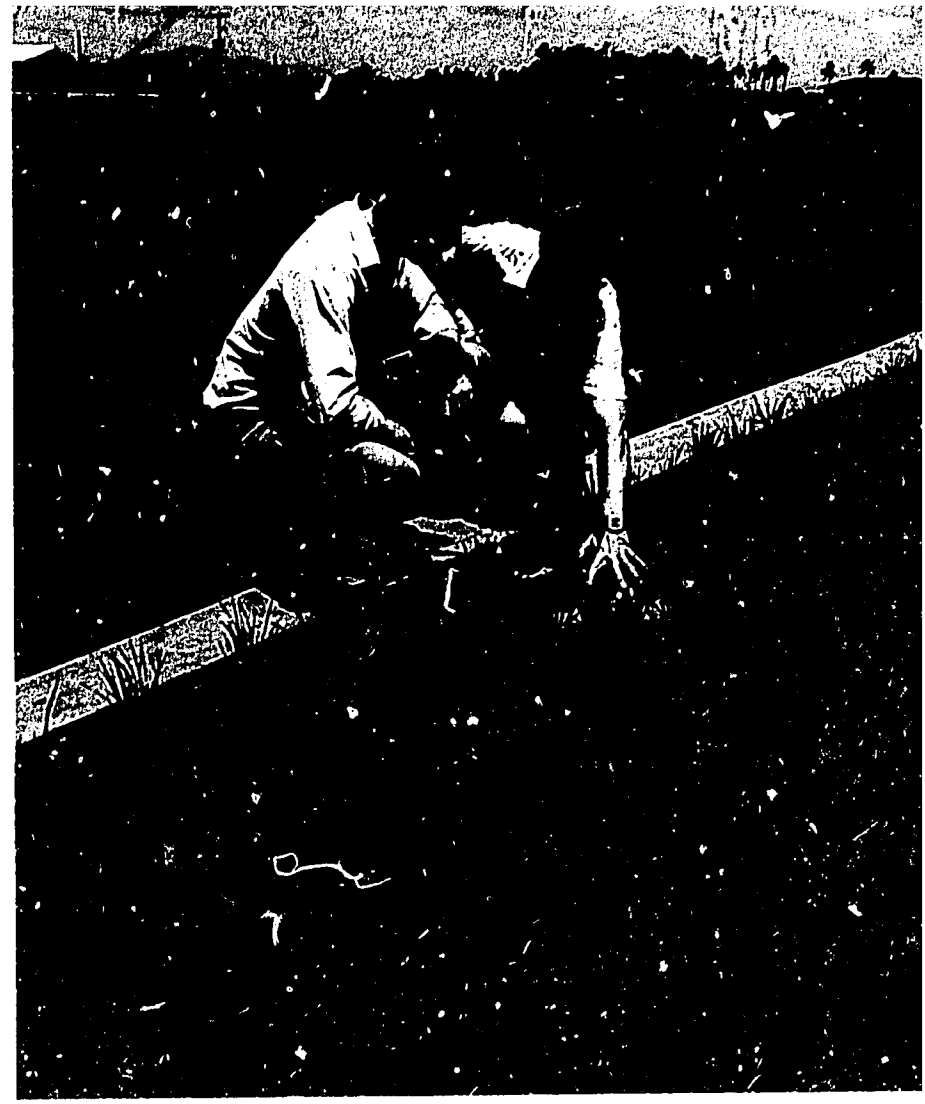
Because the efficiency of nitrogen fertilizers applied to flooded rice fields is often very low, valuable resources are lost and food production is reduced. Increasing this efficiency by developing improved nitrogen fertilizers and better management practices would benefit both the individual farmers and the nations. IFDC's lowland nitrogen research program was designed to develop a clearer understanding of the factors that affect nitrogen efficiency and to develop a means of overcoming problems as they are identified. Since 1979 an IFDC staff member has been stationed at the International Rice Research Institute (IRRI) to strengthen the field research in this area.

Causes of Poor Nitrogen Efficiency

Ammonia Volatilization—The form of nitrogen (urea or ammonium sulfate) applied affects the rate at which ammonia is volatilized from the floodwater treated with either fertilizer. These rates were determined in the field by use of micrometeorological techniques. The major objectives were to determine the amount of ammonia evolved from the ammonium sulfate treatment and to confirm the importance of ammonia volatilization as a nitrogen loss mechanism where urea is used. In addition, a detailed analysis of the floodwater was made to determine which factors control the ammonia loss from either source. The amounts of ammonia evolved from urea and ammonium sulfate were measured simultaneously.

Ammonia loss from floodwater treated with urea reached a maximum 3 days after application and then steadily declined over the next 5 days. The total amount volatilized was about 36% of the nitrogen applied. Where ammonium sulfate was applied to the floodwater, the maximum rate of loss occurred on the first day after the fertilizer application. The rate of loss declined rapidly after the fourth day. The total amount was equivalent to 37% of the nitrogen applied. Therefore, the amounts of ammonia volatilized from the two sources were similar when measured in the same field; however, the timing of the losses were different.

Other factors that affect ammonia volatilization were measured, such as the percentage of ammoniacal nitrogen in the floodwater, as well as the temperature, pH, and alkalinity of the floodwater in an effort to determine the principal causes for such volatilization. These measurements suggest that many of the field floodwater systems accumulate enough alkalinity from irrigation water to maintain modest rates of ammonia losses from ammonium sulfate, ammonium chloride, or other fertilizers containing ammoniacal nitrogen. Large losses of ammonia are probably not restricted to urea sources, at least where nitrogen fertilizers are topdressed to irrigated paddies. Repeated sampling of the floodwater for chemical analysis revealed that interactions between the



Dr. Paul L.G. Vlek, Director (left), IFDC Agro-Economic Division, and Dr. I.R.P. Fillery, Soil Scientist, examine microplots for measuring gaseous nitrogen losses in wetland rice fields.

Philippine laborers transplant rice plots for a fertilizer applicator trial at IRRI.

ammoniacal nitrogen concentration, pH, and total alkalinity were the primary factors controlling the rate of loss.

Denitrification—Denitrification is the process by which nitrate nitrogen is lost from the soil to the atmosphere as nitrogen gas or as nitrous oxide, and it is widely believed to be a major loss mechanism from both flooded and upland soils. IFDC soil scientists have developed a new technique to measure the amounts of nitrogen lost from the soil to the atmosphere through denitrification by incorporating an isotope of nitrogen (^{15}N) in the fertilizers. The new technique involves "fixing" the nitrogen with an electric arc to a form that is easily measured so that the isotopic composition of the gases evolved from the soil can be determined and thus the amount of denitrification can be measured.

Past field research has shown that ammonia volatilization is the major loss mechanism in many locations. However, recent results suggest that when this mechanism is reduced denitrification losses may increase. This is probably because more fertilizer nitrogen is available to the microbial organisms that cause the nitrification-denitrification process.

Also involved in the rate of fertilizer losses is the soil management practice of puddling, a common practice for Asian rice farmers. Puddling is the result of tilling wet soil and, thus, destroying its structure. This practice, coupled with varying soil-water regimes from deep water to drought in the rainfed rice system, can increase the loss of applied nitrogen fertilizer by the nitrification-denitrification process. Research was conducted in 1983 to determine the effects of puddling on nitrogen losses and on the performance of urease and nitrification inhibitors in the intermittently flooded soils.

A laboratory study conducted at Headquarters showed that nitrogen-loss mechanisms were affected by puddling and by using the urease inhibitor, PPD. However, no significant effect of DCD, a nitrification inhibitor, was observed in either the puddled or structured soils. By 14 days after a urea application, ammonia volatilization losses in the puddled soil were slightly higher than in the structured soil, 47% and 38% of the applied urea, respectively. However, no significant difference was found in the total denitrification losses of untreated urea in the puddled and structured soils.

Ammonia volatilization losses were decreased by the addition of PPD in both the puddled and structured soil systems although about 20% of applied urea was still lost via this mechanism. Nitrification-denitrification became a more important loss mechanism when the urease inhibitor, which reduced the ammonia volatilization loss, was present. Further research is needed to determine the magnitude of denitrification loss of applied urea plus PPD in different soil and water management systems with rice plants.

Evaluation of Products

Urease Inhibitors—One approach to increasing urea efficiency is to put a urease inhibitor into the urea. The inhibitor delays the conversion of urea to ammonia, which can subsequently be lost by volatilization. This loss is estimated by IFDC to be as high as 40%-50% of the urea applied to flooded rice. By keeping the nitrogen as urea, it can then enter the soil where it would be better absorbed and not lost. IFDC concentrated much research effort into this promising area in 1983.

The most effective urease inhibitor found to date is PPD. In greenhouse experiments designed to directly measure ammonia volatilization, the addition of 1% PPD in the urea decreased volatilization to about 5% of the urea, while without PPD the losses were 32%. This reduction in nitrogen losses from urea applied to flooded rice caused increased yields (Figure 1) for applications made early during the growing season, while later applications tended to decrease yields slightly.

Nitrogen uptake, however, was increased at all timings of application by the addition of PPD (Figure 2). The increase of nitrogen uptake early in plant growth caused yield increases, while the increased uptake of later application did not increase the grain yield. Further work on the effect of PPD and timing of urea application is needed since these factors may greatly affect the efficiency of urea applied to rice.

In field trials the effects of PPD on the hydrolysis of urea, plant uptake of nitrogen, ^{15}N recovery, and ammonia volatilization were evaluated in a series of experiments conducted in the Philippines at the Maligaya Rice Research Training Center and IRRI, respectively.

PPD delayed the hydrolysis of urea and retarded the buildup of ammoniacal nitrogen in all studies. However, there was no effect on the pH in the floodwater which followed a

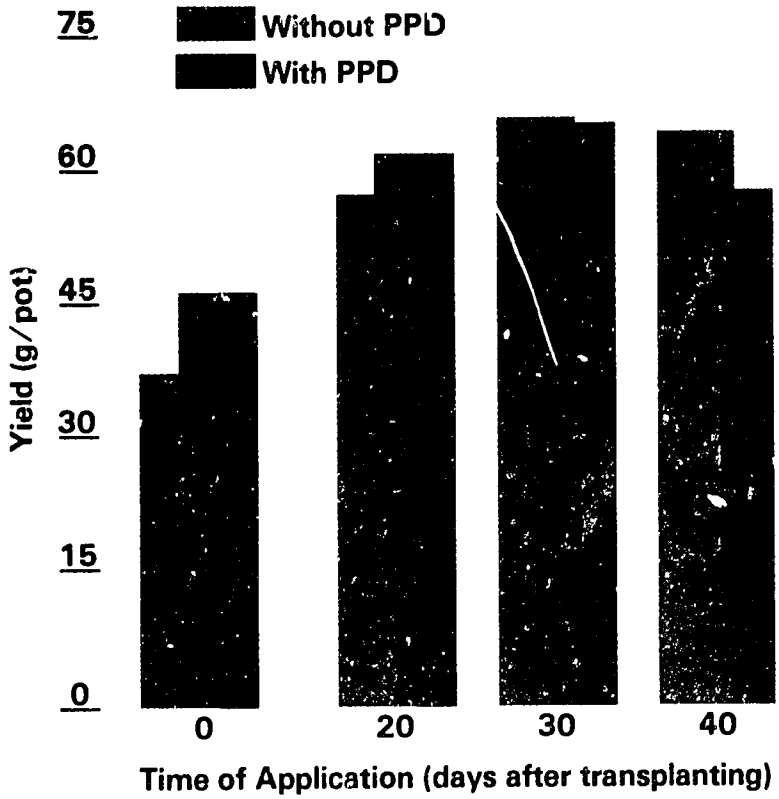


Figure 1. The Effect of PPD Addition to Urea on Rice Yield, Greenhouse Study.

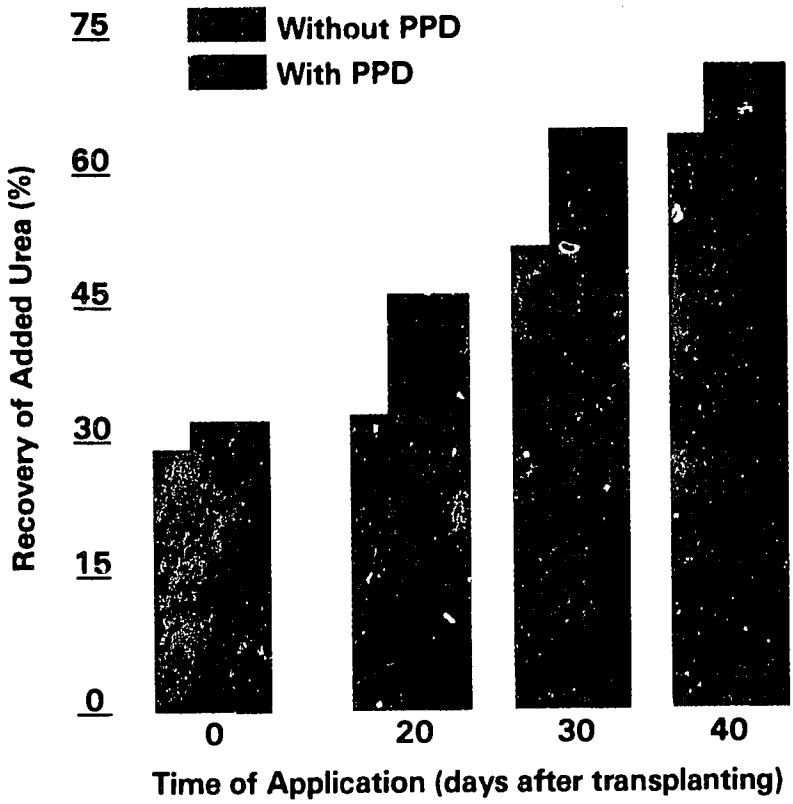


Figure 2. The Effect of PPD Addition to Urea on Fertilizer N Recovery, Greenhouse Study.

daily pattern throughout the tests. Plant uptake of nitrogen and grain yield were significantly enhanced in an IRRI experiment where urea and urea plus 1% PPD were topdressed 26 days after transplanting. Grain yield was not enhanced in a comparable experiment at Maligaya where urea and urea plus 1% PPD were applied 18 days after transplanting.

IFDC also conducted ^{15}N balance studies at Maligaya and IRRI to evaluate the effect of PPD on nitrogen loss from topdressed urea. Application of PPD (1% w/w) with urea increased ^{15}N recovery by 14% and 12% of the nitrogen applied at Maligaya and IRRI, respectively.

In the IRRI study, the increased nitrogen recovery was obtained in the plant pool, while at Maligaya, the exchangeable ammonium fraction contained more ^{15}N where PPD was applied with urea.

Time of application of urea plus PPD may be an important factor affecting the distribution of ^{15}N in the plant-soil system and grain yield response. IFDC is currently initiating research to evaluate this point.

In a micrometeorological study, the application of PPD (1% w/w) with urea reduced the ammonia loss from 22 kg N/ha to 12 kg N/ha where 58 kg/ha of urea was applied to floodwater 18 days after transplanting. The ammoniacal nitrogen in the floodwater was maintained at low concentrations for 3 days following the application of urea plus 1% PPD. However, substantial concentrations were detected on the fourth day, and the maximum concentration of ammoniacal nitrogen (12 μg N/ml) was obtained on the sixth day of the study. These results indicate that PPD inhibited urea hydrolysis for only 3 days in this study.

Experimental Nitrogen Fertilizers—Several experimental nitrogen fertilizers were evaluated in the IFDC Headquarters greenhouses in 1983 (Figure 3). Of these, several show promise. In this trial guanylurea sulfate, an organic nitrogen compound, showed a significant yield advantage over urea when both were broadcast and incorporated before transplanting. Research on this and related compounds is expected to be increased in the future.

The use of urea-metal complexes with copper and zinc resulted in some yield increase. The mechanism by which these metals may reduce losses and increase yield is not fully understood; however, it is known that they may affect urea hydrolysis and algal growth in the floodwater. Zinc and copper are also essential micronutrients and may, under some circumstances, increase yields by alleviating a micronutrient deficiency.

IFDC also tested several slow-release compounds, called urea-formaldehydes (ureaforms) in 1983. These products were made by use of a new process developed by IFDC chemists. The process is much simpler than current methods of manufacturing ureaforms and has an additional advantage of producing shorter molecular chains of urea than those of commercial processes, which form long chains that release nitrogen too slowly for agronomic crops. An initial greenhouse study with both upland and flooded rice showed promising results with the ureaforms produced by the new process. The release or mineralization of the nitrogen compounds was considerably faster than from the commercial products. Further studies with the materials will be conducted to determine whether the new products can decrease the losses of the fertilizer nitrogen relative to urea and thereby increase fertilizer efficiency.

Other Products—IFDC scientists evaluated the effect of urea source and nitrification inhibitor on nitrogen uptake and grain yield in a simulated rainfed study that used a linesource sprinkler to vary the water input. They evaluated urea sources that included urea supergranules (point deep placed), prilled urea, and SCU (basally incorporated). DCD was also added to prilled urea and basally incorporated or compacted with urea to form urea-DCD briquettes, which were point-placed 8-10 cm deep. There was a significant increase in grain yield for all water regimes where nitrogen was added. Deep placement of urea supergranules and basal incorporation of SCU gave slightly higher grain yields than did the split urea treatment (two-thirds basal and one-third at panicle initiation). Application of DCD did not affect grain yield.

New Collaborative Projects

IFDC initiated cooperative work with the Indian Council of Agricultural Research to evaluate nitrogen materials and fertilization practices in three diverse areas of India. The scientists will use labeled nitrogen (^{15}N) in these experiments. The labeled nitrogen gives researchers much greater ability to trace what happens to the fertilizer than ordinary fertilizer does.

The scientists came to IFDC to make final plans for the experiments and to learn the specialized techniques of labeled nitrogen research. This collaborative work will provide valuable information to IFDC scientists and help to introduce an important tool for nitrogen research in India.

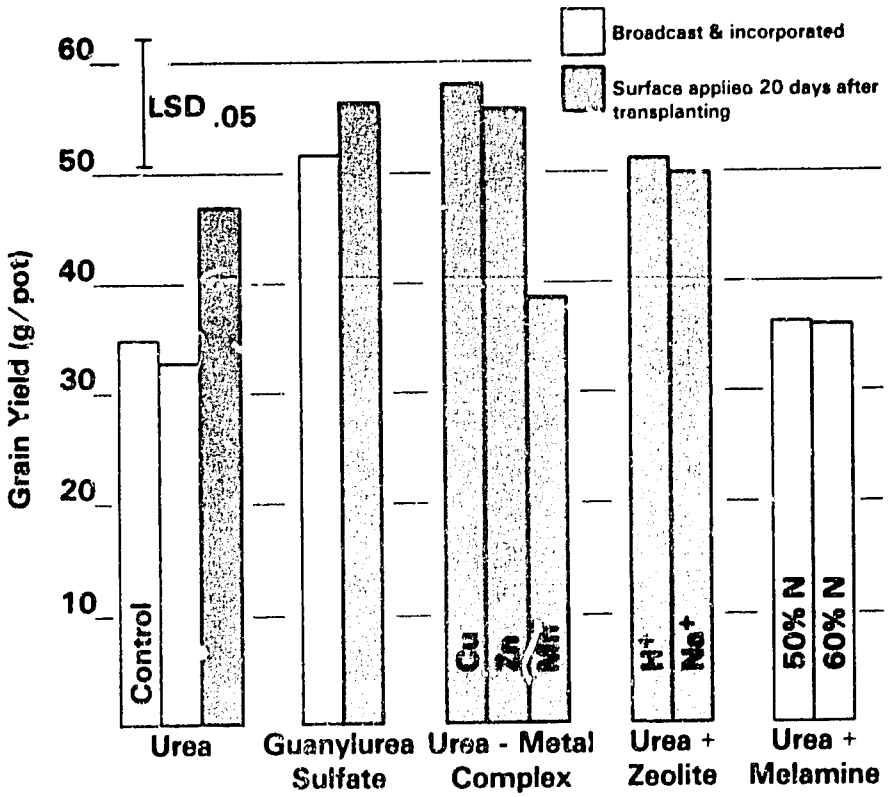


Figure 3. Grain Yield Resulting From Use of Experimental Nitrogen Fertilizer Under Two Managements.

Upland Nitrogen Program

The upland nitrogen research program focuses on principal food crops in the tropics other than flooded rice. Since nitrogen fertilization problems in developing countries depend upon climatic and crop-growing conditions, IFDC established this program following the agroclimatic zonation adopted by the CGIAR. The zones identified for investigation are the humid tropics, the subhumid tropics, the semiarid tropics, and the Mediterranean-type environments. Research priority was given to rainfed agriculture since the poorest farmers are generally those engaged in rainfed agriculture. Research has focused mainly on maize, sorghum, millet, and wheat.

The objective of the upland research program is to identify effective fertilizer sources and fertilizer management practices to increase crop yields. The research approach has been to determine the losses and efficiency of crop uptake for nitrogen fertilizers and then to develop improved fertilizer sources and fertilization practices to overcome losses and increase recovery of applied nitrogen by crops.

Evaluation of Products and Practices

Previous IFDC research results suggested that ammonia loss from broadcast urea might be a problem on certain upland soils. Since deep-placed urea supergranules were effective in reducing ammonia loss from flooded rice paddies, IFDC was interested in determining the merit of deep-placed urea for upland crops.

In the Headquarters greenhouses, IFDC scientists examined the influence of urea placement and urea granule size on nitrogen fertilizer loss with sorghum. Urea was either (a) point placed 10 cm from the plants at a soil depth of 6 cm, (b) banded along a line 8 cm from the plant row at a soil depth of 6 cm, or (c) broadcast on the soil surface. Urea was added as a powder and four different granule sizes. The quantities of added nitrogen not recovered in the soil and sorghum and presumably lost in gaseous form are given in Figure 4. Nitrogen losses were dramatically lower for banded and point-placed urea than for broadcast urea. Granule size had no effect on loss from banded and point-placed urea. The main loss mechanism from broadcast urea was presumably ammonia volatilization. Band and point placement was very effective in reducing nitrogen loss on this soil.

Further studies showed that ammonia loss from deep-placed urea supergranules was strongly influenced by soil type. Ammonia loss from 1-gram urea supergranules placed at a 4-cm soil depth was directly measured in pots with an

Indian field workers mix soil prior to sampling for chemical analysis.

airflow across the soil surface. The soil surface was wetted periodically, and the pots were sealed to prevent leaching loss. Ammonia loss over a 5-week period ranged from 3% on a sandy clay loam soil from India to 64% for a sandy soil from Niger (Table 1). The results suggest that the potential for ammonia loss from urea supergranules is very large on light-textured soils with little capacity to adsorb ammonia. Heavy rainfall, sufficient to leach the urea and ammonia down the soil profile, would likely reduce the ammonia loss.

Another subject receiving consideration at IFDC is soil acidity. Soil acidity is recognized as an important constraint to crop production throughout the world, but the problem is most acute in humid tropical regions. Continuous use of nitrogen fertilizers accelerates acidification of the soil because hydrogen ions are generated during nitrification of ammonium-form fertilizers and because nitrates leach basic constituents from the soil. Acidification of soil leads to aluminum toxicity through dissolution of soil minerals; this is a major factor contributing to the infertility of acid soils. Aluminum levels as low as one part per million have been shown to drastically reduce crop yields in highly acid soils.

Detailed studies of the acidification of an Alfisol from the International Institute of Tropical Agriculture (IITA), an Ultisol, and an Oxisol from CIAT are being conducted in the laboratory at IFDC. The experiment encompasses four simulated years of nitrogen application and leaching condensed into one year. Acidification due to applied urea, CAN, ammonium sulfate, calcium cyanamide, and control treatments is being compared on each soil. These studies are not complete, but preliminary results indicate that nitrogen application has already had a dramatic effect on soil acidity and ion composition of leachates.

Field Research in India—IFDC scientists evaluated urea, deep point-placed urea supergranules, potassium nitrate, ammonium nitrophosphate, and diammonium phosphate with sorghum during the rainy season at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India. Nitrophosphate is produced in India. Potassium nitrate was included to examine the potential for denitrification and leaching losses. In past field research the greatest grain yields and lowest fertilizer losses with urea were obtained when the urea was applied twice (split-applied) rather than all at planting time and placed 6-8 cm deep in the soil near the crop row (banded). This band split application method for urea was used as a reference treatment in the experiments. In 1982 the experiment was conducted on a deep black clay soil (Vertisol); in 1983 the experiment was on a shallow black clay soil (Vertic Inceptisol). Rainfall during the growing season was 510 mm

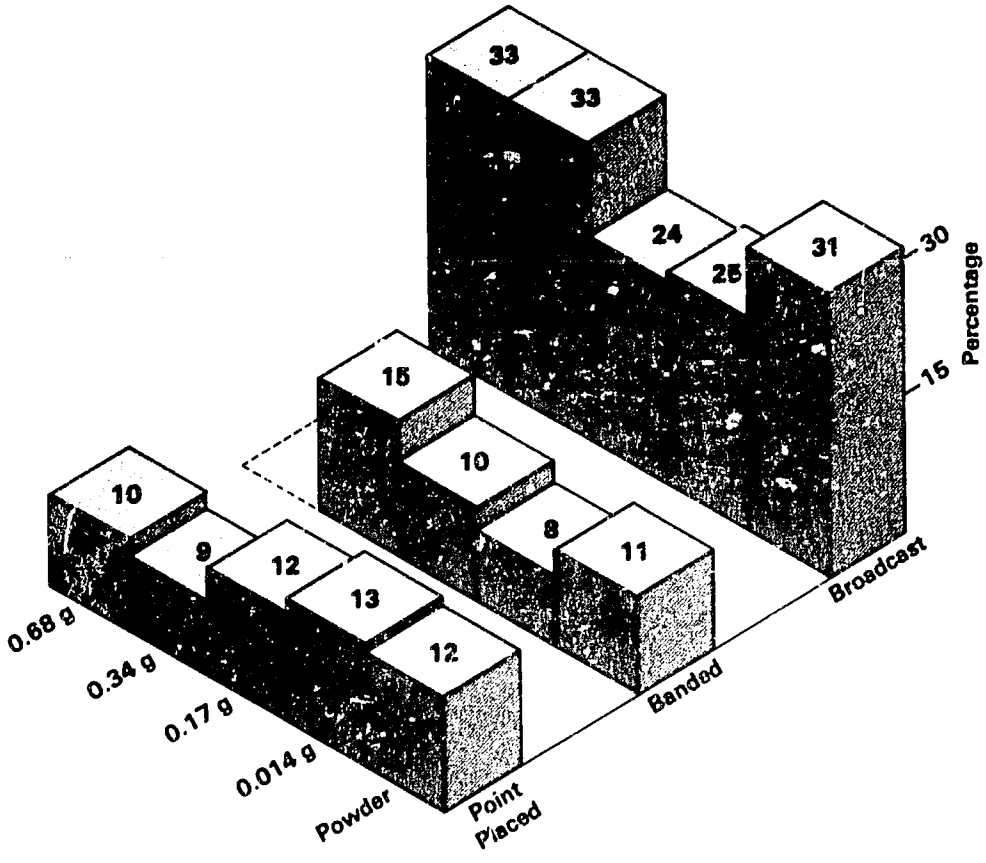


Figure 4. Influence of Urea Granule Size and Urea Placement on Nitrogen Fertilizer Loss From a Clay Soil Cropped With Sorghum.

Table 1.
Influence of Soil Type on Ammonia Loss Over a 5-Week Period From Urea Supergranules Placed at a 4-cm Soil Depth

Soil				
Texture	Location	Paste pH	CEC	Added Nitrogen Loss as NH_3
			(meq/100 g)	(%)
Sandy loam	United States	5.5	7	27
Sandy clay loam	India	5.9	18	3
Sand	Niger	4.9	2	64
Loamy sand	Nigeria	6.9	5	61
Sandy clay loam	Nigeria	6.2	11	23
Sandy loam	Nigeria	5.3	14	4

and 913 mm in 1982 and 1983, respectively. During 1982 no difference in yield was observed among the split-applied nitrogen sources investigated (Table 2). Application of urea on the soil surface, one-half at planting and one-half at 4 weeks after planting (broadcast split), was inferior to all other application methods. Loss of applied nitrogen presumably as ammonia gas was likely a problem in this application practice.

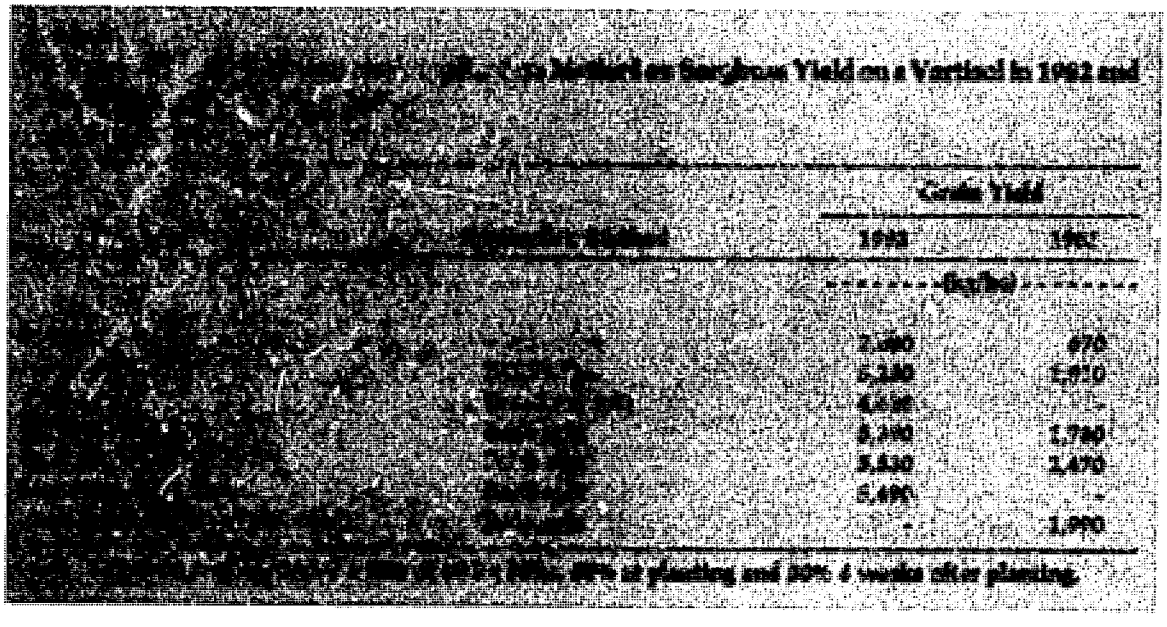
The results for the shallow black soil in 1983 were quite different from those obtained on the deep black soil in 1982. Yields were much lower on the shallow black soil. The urea supergranule was superior to conventional urea and other

nitrogen sources evaluated on the shallow black soil.

Field Research in Sub-Sahara Africa—Field experiments were conducted on thirteen sites across sub-Sahara Africa in 1983 to study the effect of nitrogen fertilizer source, management, and application rate on the production of food crops. These experiments were conducted in collaboration with IITA, ICRISAT, and several national agricultural research centers of Africa. Typically, the nitrogen management experiments consisted of increasing rates of urea and CAN. Management of nitrogen encompassed basal and split applications of broadcast incorporated and banded granular urea as well as point-placed urea supergranules.

Results from some trials in the different agroclimatic zones of Africa are now being analyzed. Differential grain yield responses to different nitrogen sources and management practices were very limited, but responses to increasing nitrogen application rates were significant at all locations. At sites where cereal crops were intercropped with a legume crop, nitrogen fertilizer application to the cereal tended to reduce legume crop yields. Further data will be gathered from similar studies in these and other locations through 1984 to confirm observations made to date.

In 1982 IFDC began collaborative research with the Agricultural Bureau of the Dutch Fertilizer Industry and IITA to study the effects of long-term applications of commonly used and modified nitrogen fertilizers to the soils of the humid tropics. The research consists of three experiments, one each at IFDC; the Institute of Soil Fertility (IB), Haren, the Netherlands; and IITA, Ibadan, Nigeria. At IITA, acidification of and nutrient uptake from an Alfisol are being compared among field plots receiving no nitrogen (controls) and plots receiving continuous applications of urea, CAN, and ammonium sulfate. Nitrogen fertilizers are being applied to maize only in maize/maize and maize/cowpea sequential crop rotation. At IB scientists from the Dutch fertilizer industry are monitoring nutrient uptake by maize, leaching of plant nutrients, and acidification of an Alfisol as affected by applications of urea, CAN, ammonium sulfate, ammonium nitrate, calcium nitrate, and magnesium ammonium nitrate (magnesamon).



Phosphate Research

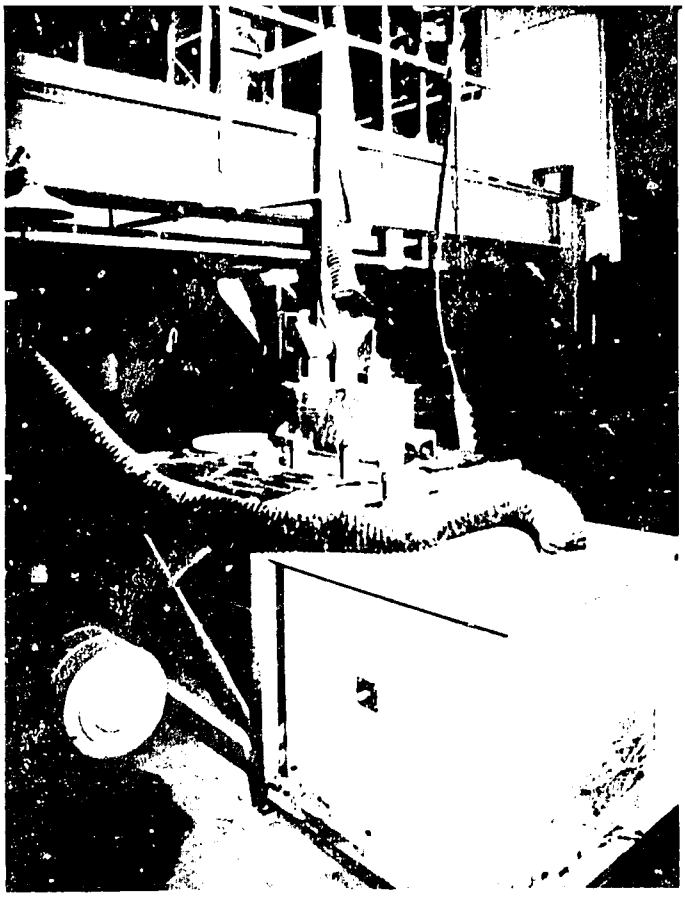
Phosphate rocks from different sources usually have significantly varying characteristics. With a newly identified phosphate ore sample (about 2 kg), IFDC performs a complete characterization to establish its chemical and mineralogical composition, texture, reactivity, and grindability. With these data some insight into its potential for use as fertilizer can be gleaned. Routes to use can be evaluated with relatively small samples (200 kg) of ore in IFDC facilities. Processing may involve fine grinding for use as a direct application fertilizer or chemical processing to produce materials such as partially or fully acidulated rock, wet-process phosphoric acid, nitric phosphates, single superphosphate (SSP), triple superphosphate (TSP), monoammonium phosphate (MAP), and diammonium phosphate (DAP).

Rock and intermediates can be combined to make multinutrient fertilizer. IFDC is also well equipped to evaluate beneficiation methods for upgrading of the ore by flotation.

One way to improve efficiency is to expend less energy in physical/chemical processing before the product is applied to the field. This stimulated interest by IFDC in evaluating alternatives such as directly applying reactive rocks and partially acidulating (using less acid) less reactive rocks for acid soils.

IFDC researchers first evaluate new or modified phosphate products in its Headquarters laboratories and greenhouses. Where justified field trials are conducted overseas through various cooperative agreements. Agronomic evaluation of phosphate products made at IFDC is heavily oriented toward Latin America and Africa. Several countries in Asia already use directly applied rock alone or in combination with other nutrients.

Phosphate agronomic research in Latin America is a collaborative effort with the Centro Internacional de Agricultura Tropical (CIAT) and in Africa with IITA and ICRISAT, where IFDC staff members are posted.



This batch pilot-scale equipment is used to produce semigranular partially acidulated phosphate rock.

Phosphate Rock Modifications

Beneficiation

Two basic phosphate ore types were studied in laboratory beneficiation tests—high silica and high carbonate. Removal of calcium and magnesium carbonates by flotation is still under experimental development. IFDC is evaluating one method for removal of carbonates by attrition scrubbing with a dilute acid. It is often difficult to obtain 1.0% or less magnesium oxide (MgO) by flotation in the concentrate from a carbonate-containing ore while obtaining a high P_2O_5 recovery.

In the laboratory IFDC technologists subjected the dolomitic Jhamarkotra ore from India to various flotation methods. They used fatty acids and their sulfonated products as dolomite collectors, with phosphoric acid, diphosphonic acid, and sodium tripolyphosphate used as phosphate depressants. Best conditions yielded a concentrate containing 35%-36% P_2O_5 and 0.7%-1.0% MgO with a recovery of 75% P_2O_5; the feed contained 16.5% P_2O_5 and 11.3% MgO. Pilot-plant tests with this ore are planned.

Partial Acidulation

Test results reported previously on partially acidulated phosphate rock (PAPR) made in a

Mr. Robert Bosheers and Mr. Benjamin Malone, IFDC technical aides, granulate multinutrient fertilizer in the IFDC Pilot Plant.

single-step process with sulfuric acid from a variety of sources in a continuous laboratory scale unit showed high efficiency of acid use, even with rocks high in iron and aluminum. The main advantages of the process are: (1) its ability to use a wide variety of rocks, (2) reduced acid consumption, and (3) less in-plant handling. The product is granular but requires drying and sizing as in a conventional granulation process.

IFDC used two rocks from the United States—Central Florida and Utah—for production of partially acidulated and granulated rock by the single-step process in the pilot plant to confirm prior results from the laboratory. IFDC researchers are using these data to develop preliminary cost estimates.

Some countries may be able to use a semigranular form of partially acidulated rock. If so, this would further reduce energy consumption and investment cost for equipment. In tests at IFDC rock is finely ground and fed continuously to a pugmill or other suitable mixer along with sulfuric acid at 30%-50% of that required to make superphosphate. The slurry discharges by gravity into a batch collapsible den for curing for about 1 hour. Off-gases are removed and treated. The solid in the den is emptied onto a pile for additional curing. Kodjari rock from Upper Volta, Parc-W rock from Niger, and Central Florida rock, United States, were used. The more reactive Parc-W and Central Florida rocks yielded products with a higher available P_2O_5 content than did the Kodjari rock at the same level of acidulation. The product was relatively nondusty, having a grainy appearance. The process is simple since no drying or granulation is needed. Tables 3 and 4 show typical partially acidulated rock products.

Use of Unground Phosphate Rock to Produce Wet-Process Phosphoric Acid

A significant part of the cost in producing wet-process phosphoric acid is the cost of rock grinding. This cost might be eliminated if a process for using unground rock can be developed. IFDC's single-tank dihydrate reactor was used to test unground rock feed from four sources—Zin (Israel), Taiba (Senegal), and calcined and uncalcined North Carolina (United States). Processing of the Taiba rock, which has medium reactivity, gave no difficulty. With the more reactive Zin and calcined North Carolina rocks, operation was more difficult, but conditions were identified for satisfactory operation. Processing the highly reactive uncalcined North Carolina rock was very difficult because "blinding" in the single-tank reactor resulted in a low filtration rate and a high P_2O_5 loss. Data from the bench-scale unit compared favorably with results from an industrial-scale operation.

Processes for Producing Multinutrient Fertilizers

Conventional Granulation

Many developing countries are now using multinutrient (NP or NPK) fertilizers, and many are considering domestic production by conventional granulation methods. The products may also contain a variety of secondary and micronutrients—typically magnesium, calcium, sulfur, zinc, and boron. The manufacture, distribution, and use of multinutrient fertilizers may present problems not encountered with single-nutrient products. Use of urea as the major nitrogen source in the formulation (1) often causes major technical problems during production because of incompatibility of the various nutrients, (2) intensifies product caking and deterioration during storage, and (3) creates concerns about nitrogen losses and agronomic deficiencies. The production of urea is increasing worldwide, and producers must use it for multinutrient fertilizer production.

IFDC, in cooperation with producers in Malaysia, Thailand, and Mexico and engineering companies in the United States and Europe, has made significant progress in identifying and solving process-oriented technical problems caused by the use of large quantities of urea in multinutrient products.

IFDC's laboratory- and pilot-scale granulation units were used in studies of use of urea in multinutrient fertilizer production. Some of this work is described under Special Projects. One product containing urea, monoammonium phosphate (made in a preneutralizer), and potassium chloride confirmed the importance of operating the process at relatively low moisture and temperature levels. Acid quality affects the operation; high purity phosphoric acid appeared beneficial. Screening and crushing of material directly from the dryer is not practical because the granules are soft (plastic).

Compaction Granulation

Studies of granulation of single and multinutrient fertilizers by pressure roll compaction of dry materials were continued. A technical bulletin entitled *Compaction: Alternative Approach for Granular*

Table 4.
Typical Granular Partially Acidulated Rock Products

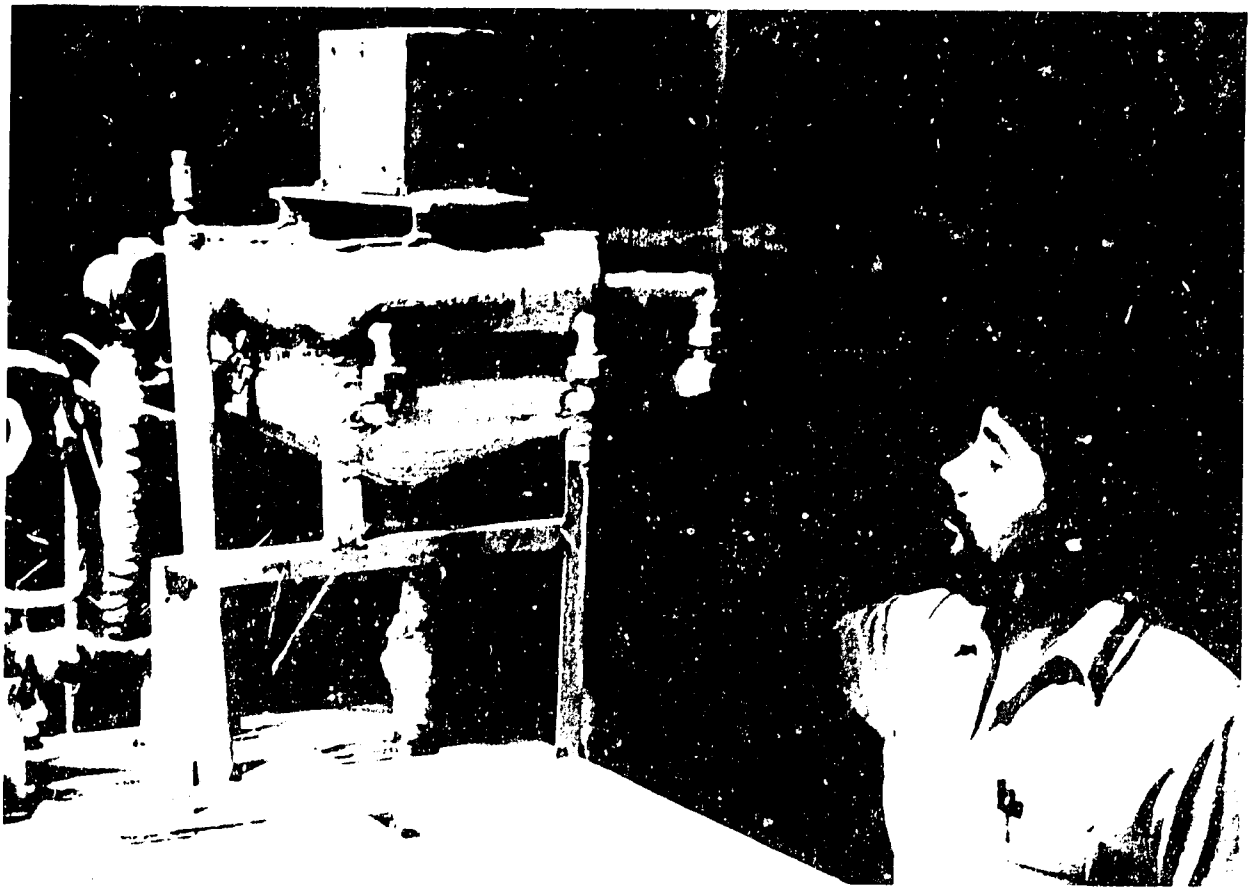
Rock Source	Level of Acidulation	Production Scale	Product Quality	Chemical Analyses: Total P_2O_5	Water-Soluble P_2O_5	NAC[b] P_2O_5	Available P_2O_5
	(%)			(wt %)			
Kodjari, Upper Volta (25.3)[a]	20	LAB	Free flowing	21.8	0.3	3.7	4.0
	30	LAB	Free flowing	21.2	0.4	4.4	4.8
	40	LAB	Free flowing	20.3	0.5	4.0	4.5
	50	LAB	Free flowing	19.7	0.8	4.7	5.5
PARC-W, Niger (26.0)[a]	50	LAB	Free flowing	21.5	9.4	1.5	10.9
Kodjari, Upper Volta (25.3)[a]	50	PP	Free flowing	18.3	1.7	4.2	5.9
	75	PP	Sticky	16.4	5.2	4.7	9.9
	100	PP	Very sticky	14.8	6.4	4.4	10.8
Central Florida, United States (32.0)[a]	50	PP	Free flowing	23.0	8.6	6.4	15.0
	75	PP	Free flowing	21.3	13.5	2.4	15.9
	100	PP	Free flowing	19.1	15.0	2.3	17.3

a. Rock total P_2O_5 (wt %).
b. Neutral ammonium citrate.

Table 4.
Typical Granular Partially Acidulated Rock Products

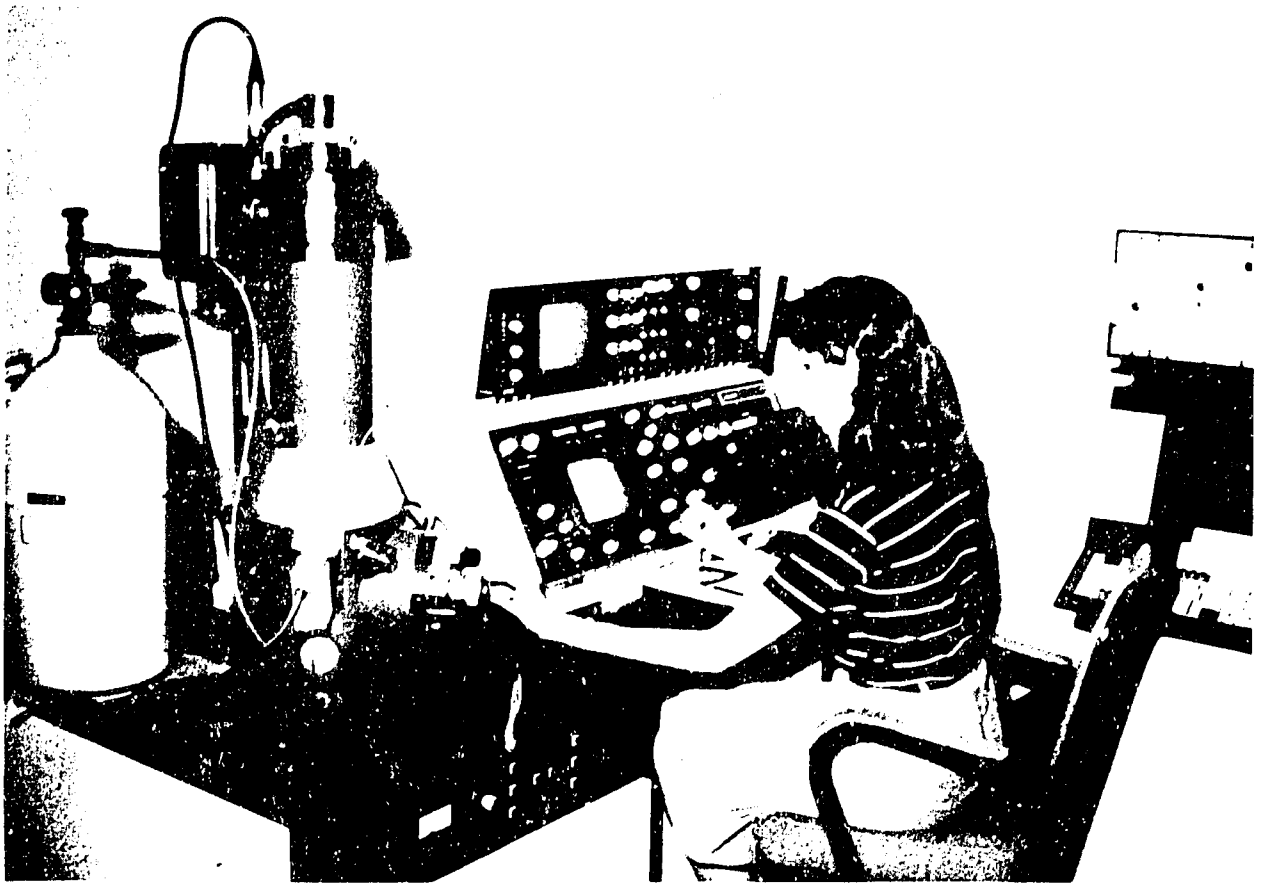
Rock Source	Level of Acidulation	Production Scale	Product Quality	Chemical Analyses: Total P_2O_5	Water-Soluble P_2O_5	NAC[b] P_2O_5	Available P_2O_5
	(%)			(wt %)			
Kodjari, Upper Volta (25.3)[a]	20	LAB	Free flowing	21.3	2.4	3.5	5.9
	30	LAB	Free flowing	20.5	2.5	3.9	6.4
	40	LAB	Free flowing	19.2	3.3	3.9	6.3
	50	LAB	Free flowing	18.0	4.5	3.0	7.5
Mikouna, Senegal (28.7)[a]	25	LAB	Free flowing	22.3	4.7	3.2	7.9
	50	LAB	Free flowing	19.8	8.0	2.8	10.8
Central Florida, United States (32.0)[a]	30	PP	Free flowing	25.6	6.8	4.7	11.5
	40	PP	Free flowing	24.5	7.7	5.4	13.1
	50	PP	Free flowing	23.7	10.9	4.1	15.0
Vernal Rock, United States (28.2)[a]	30	PP	Free flowing	24.3	7.3	2.2	9.5
	40	PP	Free flowing	24.0	8.9	3.5	12.4
	50	PP	Free flowing	23.5	11.1	1.8	12.9

a. Rock total P_2O_5 (wt %).
b. Neutral ammonium citrate.



Dr. Amitava H. Roy, IFDC Special Project Engineer, is pictured with a specially designed low-biuret urea melter used for feeding urea melt to the multinutrient fertilizer granulation unit.

Ms. Michelle Cooper-Fleck, Mineralogist, examines a phosphate rock sample using the scanning electronic microscope.



Fertilizer was published. In this bulletin compaction is compared with steam-water granulation, and savings in investment and energy consumption for compaction are indicated. A continuous unit with a capacity of about 20 kg/h is installed at IFDC. The process appears suitable for a wide range of dry, free-flowing materials that do not chemically react after the granules are formed.

IFDC evaluated an interesting application of compaction for Haiti. Multinutrient fertilizers were made from urea, MAP, potassium chloride, and an organic compost filler. The compost was made in Haiti from waste fruit peels collected from the streets. Granules of a 20-20-10 product were strong but somewhat hygroscopic when using dried compost (2.5% H_2O). About 20% of the formula weight could be supplied as compost to replace relatively expensive sand normally used as filler. The process may be used commercially in Haiti to supply the domestic market.

Laboratory and Greenhouse Research

At Headquarters IFDC scientists studied the influence of the phosphorus-sorption capacity of the soil on the relative agronomic effectiveness of finely ground phosphate rock and of PAPR as compared with conventional high-solubility phosphorus-containing fertilizer. Scientists usually assume that the agronomic effectiveness of phosphate products of low solubility such as phosphate rock used in the tropics should increase relative to high-solubility products as the phosphorus-sorption capacity of the soil increases. This is based on the logic that since the rate of dissolution of phosphate rock is slow, the phosphorus will be "protected" against the rapid conversion to plant-unavailable reaction products in the soil, as is the case with fertilizers such as TSP. Previous research had also shown that while the rate of phosphate rock dissolution remained low, it did increase in soils with high phosphorus-sorption capacity as a result of the more rapid removal of phosphorus from the soil solution surrounding the rock particles.

It was observed in experiment station research conducted in Latin America, however, that the effectiveness of phosphate rock was highest in the acid Oxisols and Ultisols with relatively low phosphorus-sorption capacity and was lower in soils influenced by volcanic ash, which exhibit extremely high phosphorus-sorption tendencies. Since these soils differed in many other properties besides the phosphorus sorption, it was not possible to determine the magnitude of the influence of this single factor from the field observations alone. IFDC researchers developed a method for adjusting the phosphorus-sorption capacity of a soil while keeping the other properties within minimal variation. They accomplished this through the use of an amorphous iron gel, which was incorporated into the soil at varying concentrations.

In a greenhouse experiment using a Mountview silt loam, pH 4.4, the iron gel was applied at three levels that resulted in a range in phosphorus sorption from the untreated condition where 33% of the applied soluble phosphorus was sorbed to the highest concentration where 59% of the applied phosphorus was sorbed. To these soils phosphorus was applied at three rates of application in the form of TSP, Bayovar phosphate rock (highly reactive), Pesca phosphate rock (low-medium reactivity) and Pesca phosphate rock, which had been acidulated with 40% of the sulfuric acid required for production of superphosphate.

With all phosphorus treatments the yield of maize decreased as the phosphorus-sorption capacity of the soil increased, but the yield reductions associated with the use of phosphate rock were more severe than those encountered with sources containing soluble phosphorus. As illustrated in Figure 5, Bayovar phosphate rock was 81% as effective as TSP at the lowest level of phosphorus-sorption capacity, but its effectiveness systematically decreased to 47% with increasing sorption levels. The less reactive Pesca phosphate rock showed extremely low effectiveness with each iron treatment, but yields were significantly increased by partial acidulation. These data are consistent with recent findings in farm-level trials in Latin America where finely ground phosphate rock was found to be ineffective in volcanic ash soils with high phosphorus-sorption capacity (see following section) and show the importance of measurements of phosphorus-sorption characteristics for identification of soils on which phosphate rock should or should not be recommended.

Nine surface soils from three west African countries (Mali, Niger, and Nigeria) constituting a transect from the very wet to the very dry agroclimates of this region were tested to determine their phosphorus-sorption capacities. These measurements indicated that the sandy soil from Niger had the lowest phosphorus-sorption capacity (36 μg of phosphorus) and this capacity was saturated at the relatively low rate of 100 μg of phosphorus per gram of soil. The highest capacity was 244 μg of phosphorus per gram of soil for a Nigerian soil derived from

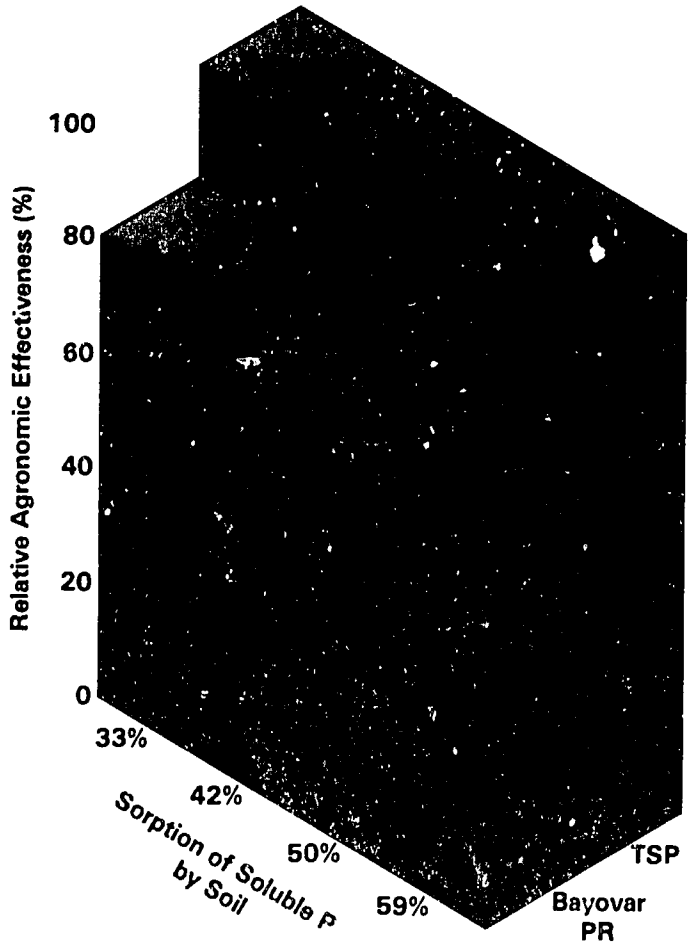
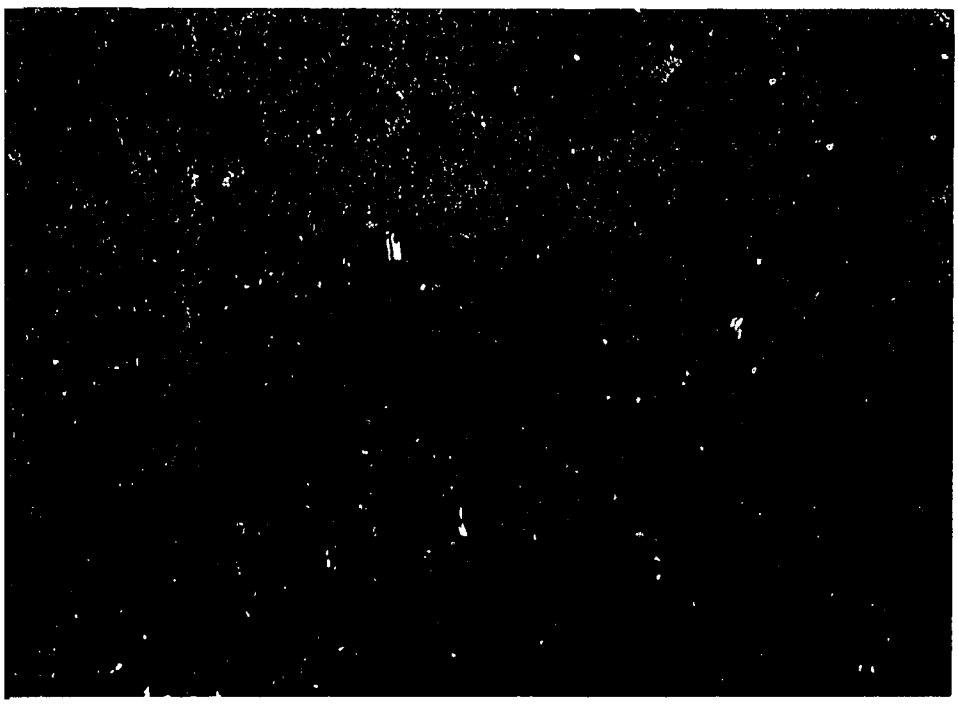


Figure 5. Relative Effectiveness of Phosphate Rock as Affected by Phosphorus Sorption Capacity of the Soil.

Dr. L. L. Hammond, IFDC Soil Scientist, examines a corn experiment conducted at Headquarters in support of field research.



basaltic parent material. The maximum values for the phosphorus sorption capacities were significantly correlated with the clay content, the oxalate-extractable iron, and the oxalate-extractable aluminum. The highest correlation ($r = 0.876$ $P < 0.01$) was between the phosphorus-sorption capacity and the sum of the oxalate-extractable iron and aluminum. The west African soils appear to have relatively low phosphorus-sorption capacities as compared with the soils from tropical Latin America; this indicates that relatively less phosphate fertilizer would be needed for optimum production of crops in these soils.

In another line of research IFDC scientists evaluated the efficiency of TSP as influenced by its physical form. The use of compaction as an alternative to conventional granulation has shown promise, and one possible application of this technology involves production of larger tablets or briquettes of either compound or single-grade fertilizers. Fertilizers in this form are expected to be adapted to a number of farm-level situations. In the Latin American steeplands, for example, fertilizer is commonly placed by the handful in the seed hole at the time of planting. Use of compaction technology in that system can provide advantages by increasing the ease of application, improving the capability to achieve uniform distribution in the field, and ensuring that nutrients applied in this localized manner are in the form required for efficient uptake by the plant. Also of importance is the fact that the products can be used without modification of the farmers' traditional application practices.

In a preliminary greenhouse experiment the efficiency of compacted TSP was evaluated by measuring the phosphorus uptake by maize when the TSP was applied as conventional granules or in compacted tablets. The phosphorus was applied at four different rates of application with the granules and either a single tablet or two tablets present at each rate. As illustrated in Figure 6, the tablets resulted in more efficient use of applied phosphorus at the lower rates of application but declined in effectiveness as the rate of application increased. This pattern is similar to the relationships encountered with band application of phosphorus when compared to broadcasting and incorporation and supports the suggestion that large tablets should be an efficient form of fertilizer for small farmers who traditionally have used less than optimum rates of fertilizers.

Additional research is being initiated to evaluate compacted fertilizers in a range of sizes and with other nutrients in addition to phosphorus.

Field Research—Latin America

Suitability of Indigenous Phosphates

A new phase of the phosphate project in Colombia was initiated in July 1982. The overall objective of the new phase is to identify phosphorus fertilizer alternatives, based on low-cost indigenous raw materials, with a high probability for availability, competitiveness, and farmer acceptance. This new phase consists of multidisciplinary research to be conducted over a 2-year period.

This phase of the project used the information obtained from the earlier research conducted under experimental station conditions to systematically evaluate fertilizers that are agronomically and economically competitive with high-cost conventional fertilizers and possess characteristics that are both adoptable and culturally acceptable at the farm level. The present research focuses on the determination of the suitability of using finely ground and partially acidulated phosphate rock from Colombia instead of processed phosphate fertilizer. During the first year of this phase of the project, definition of management requirements of alternative phosphorus fertilizers is providing the basis for subsequent outreach and extension programs.

The project is centered at the facilities of CIAT in Palmira, Colombia. One IFDC soil scientist and one sociologist, in collaboration with Instituto Colombiano Agropecuario (ICA) scientists in each of the regions selected, designed, established, monitored, and evaluated the on-farm trials. The project economist is conducting cost and benefit analyses as the on-farm evaluations are in progress. ICA's Rural Development personnel are also collaborating in the collection of sociological and economic data as well as the analysis and evaluation of the results.

On-Farm Evaluations

Three regions were selected as representative of the three different agroclimatic zones, which are typical of Latin America: midaltitude, highland, and lowland tropics.

The crops that were selected for these experiments included bush beans, cassava, maize, potatoes, and upland rice. Three phosphate fertilizers were included in the evaluation experiments—TSP, finely ground Huila phosphate rock, and partially acidulated (50%) Huila phosphate rock. In the case of rice in Villavicencio (lowland tropics), finely ground Pesca rock, and partially acidulated (40%) Pesca rock were also included in the experiments. The cooperating farmers planted the trial crops in each of the

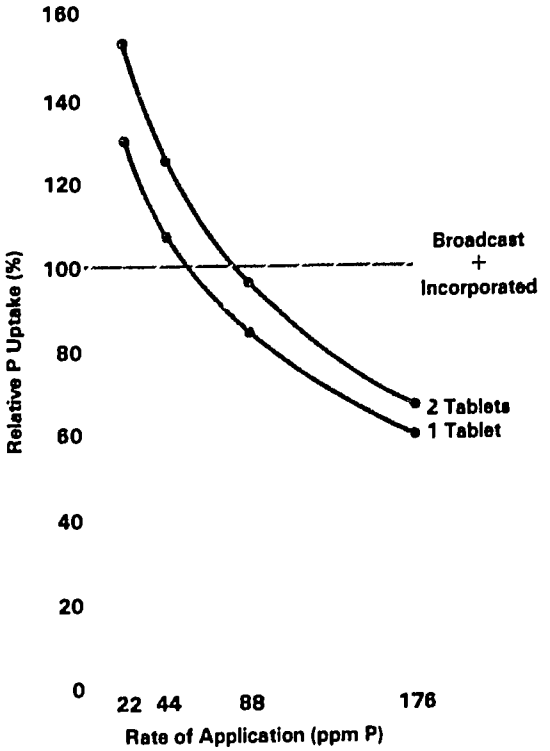


Figure 6. Efficiency of TSP as Influenced by Placement in a Greenhouse Experiment With Maize.

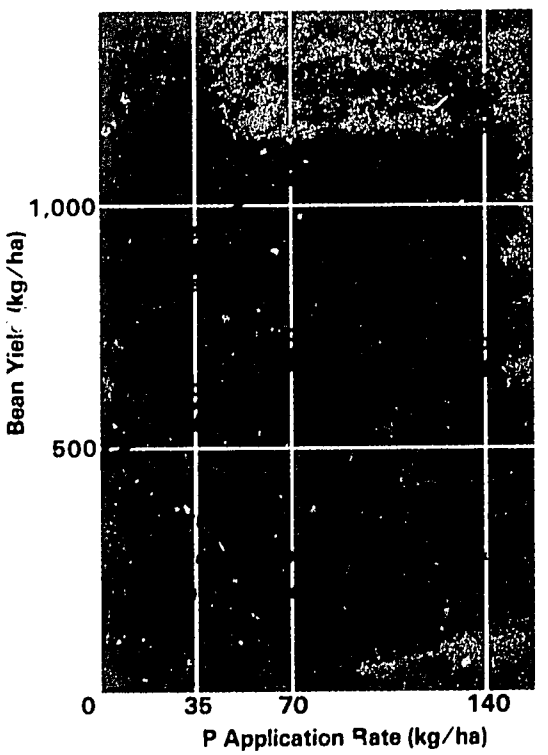


Figure 7. Response of Beans to Phosphorus Sources and Rates, Grown in Acid Inceptisols From Pescador, Cauca. (Means with same letter, among phosphorus sources for each application rate, are not significantly different. Duncan's multiple range test was used for variable: grain yields).

locations in collaboration with ICA and project personnel. Planting procedures and subsequent management practices were selected by the researchers from a preliminary survey and carried out by the farmers. Collaborating farmers also have participated in the selection of the site and variety of seed planted, fertilizer used, land preparation, plot demarcation, soil sampling, and fertilizer application.

Effect of Phosphate Fertilizers in Different Cropping Systems

The mean production rates of bush beans at 14 experimental sites are shown in Figure 7. There was no statistically significant difference between the yields obtained with PAPR and those obtained with TSP. At all phosphorus application rates the finely ground phosphate rock from Huila produced the lowest yields, and they were significantly different from the yields obtained with the more soluble phosphate. Increasing the phosphorus application rates increased the yields in all instances; the highest yield occurred at a phosphorus application rate of 140 kg P/ha.

Crops like potatoes, beans planted with maize, and upland rice responded well to applications of phosphate fertilizers. The first potato crop responded best to the highest rate of phosphorus application (180 kg P/ha) in the form of PAPR. With the other crops the yields were generally as good at the lowest phosphorus addition rate as at the higher rates regardless of the source of the phosphate. Two other factors affected the yields—length of the life cycle of the crop (which depends on the altitude) and the acidity of the soil.

Upland rice grown in the Oxisols of Villavicencio responded as well to the finely ground phosphate rocks from Pesca and Huila as to TSP or partially acidulated Pesca or Huila phosphate rocks.

Test results indicate that for crops having short life cycles (3 months) grown in soils of relatively high phosphorus-fixation capacity, the soluble phosphate fertilizers are better than the phosphate rocks with low-to-medium reactivities. For crops having longer life cycles (4 to 12 months) grown on Andepts and Oxisols that have a relatively low phosphorus-fixation capacity, the finely ground phosphate rocks perform agronomically as well as the more soluble phosphorus sources like TSP and PAPR.

An ongoing socioeconomic study will provide additional information to help decide which of the above sources of phosphorus is most suitable for the small- and medium-size farmers in the various areas of Latin America.

Estimated Costs of Partially Acidulated Huila and Pesca Phosphate Rocks

Preliminary estimates of the costs of producing, distributing, and marketing of granular 50% acidulated Huila and Pesca phosphate rocks were obtained as a first step of the economic evaluation of using these fertilizers as alternative sources of phosphorus for crop production in selected locations of Colombia. These estimates showed that (1) the total capital investment required to produce PAPR is substantially smaller than the one needed to produce TSP, DAP, and NPK fertilizers although the fixed costs per ton were higher, (2) reserves of Huila and Pesca phosphate rock are suitable to produce PAPR, but they might not be large enough to justify the large investment required to produce TSP, DAP, and NPK fertilizers, (3) PAPR could be a cost-effective source of phosphorus for the acid soils of Colombia compared with the costs of phosphorus supplied by the domestically manufactured and widely used NPK compounds 10-30-10 and 13-26-6, and (4) the production of PAPR from Huila and/or Pesca could reduce the imports of phosphate fertilizers, save foreign exchange, and provide additional employment in Colombia.

Field Research—Africa

The year 1982 marked an escalation of IFDC's Africa fertilizer program. It also marked the fifteenth time in the past 20 years that per capita food production has declined in sub-Sahara Africa. There is little doubt that the slow growth in agriculture is at the heart of the overall development problems in Africa. To make agriculture a dynamic sector requires a combination of ingredients including viable technical packages adapted to local conditions, timely availability of key inputs such as fertilizers, effective research and extension services, and reasonable pricing policies.

IFDC's Africa Fertilizer Program, supported financially by the International Fund for Agricultural Development (IFAD), ended its second year of field research in 1983. In the Republic of Niger, our outposted scientists set up experiments at the ICRISAT Sahel Center farm at Sadore and in farmers' fields in Gobery and Sadeize Koira to evaluate the agronomic performance of partially acidulated PARC-W phosphate rock compared with commercial single superphosphate. Cowpea was grown in the Sadore experiment while millet was grown at both Gobery and Sadeize Koira. At all sites, 50%

partially acidulated PARC-W phosphate rock was as effective as SSP for crop production. In similar trials using 40% partially acidulated PARC-W phosphate rock, scientists from the Institut Nationale Recherches Agricoles du Niger, working collaboratively with IFDC scientists, found that PAPR was as effective as SSP at both Mai-Gamji and Hamdalaye.

The agronomic effectiveness of finely-ground Togo phosphate rock and Togo PAPR was evaluated in several experiments in Nigeria by our IITA-based scientist. Responses to phosphorus were obtained at both Ikenne in the humid region of Nigeria and at Mokwa in the Southern Guinea savanna region. The results of these experiments indicate that at Ikenne PAPR was inferior to TSP, but at Mokwa PAPR outyielded TSP. PAPR was also evaluated against DAP and 15:15:15 at three sites on the World Bank-supported Akoko-Ekiti Agricultural Development Project in southwestern Nigeria. At two of the three sites where there was response to phosphorus, the highest yields were obtained with PAPR (Table 5).

The performance of Togo PAPR was also evaluated in collaborative trials with national scientists in Kenya, Togo, and Cameroon. The response of beans (*phaseolus* spp) and maize in Kenya and of maize in Togo to PAPR continues to support the view that agronomically PAPR is a viable phosphate fertilizer alternative for sub-Sahara Africa.

One of our objectives in the Africa Fertilizer Program is to carry out agronomic trials to ascertain the phosphorus needs of the soils and crops of the region. Studies undertaken at Sadore show that, in the first year of phosphorus application, 13 kg P/ha appears optimum for millet. Modest dressings of superphosphate (9 kg P/ha) provide high amounts of residual phosphorus (Figure 8).

The relative need for different nutrient elements in soils of various regions of Niger is being evaluated in simple demonstration trials at several locations. Information gathered from these trials over 2 years suggests that phosphorus is the key limiting nutrient in the soils of Niger. Also, fertilizers that do not contain sulfur perform poorly in these soils.

Maintenance of soil fertility on a long-term basis is a key element of the management of the chemically fragile soils of sub-Sahara Africa. In 1983 our Niger-based scientists set up a long-term trial on crop residue management and soil fertility maintenance in the presence or absence of mineral fertilizers. The first year's results, summarized in Figure 9, indicate that highest crop yields are obtained by a judicious combination of chemical fertilizers and crop residues. In a fertility maintenance trial in Nigeria, it was found that under conditions of low soil fertility maize gave higher yields when intercropped with cowpea than when grown alone.

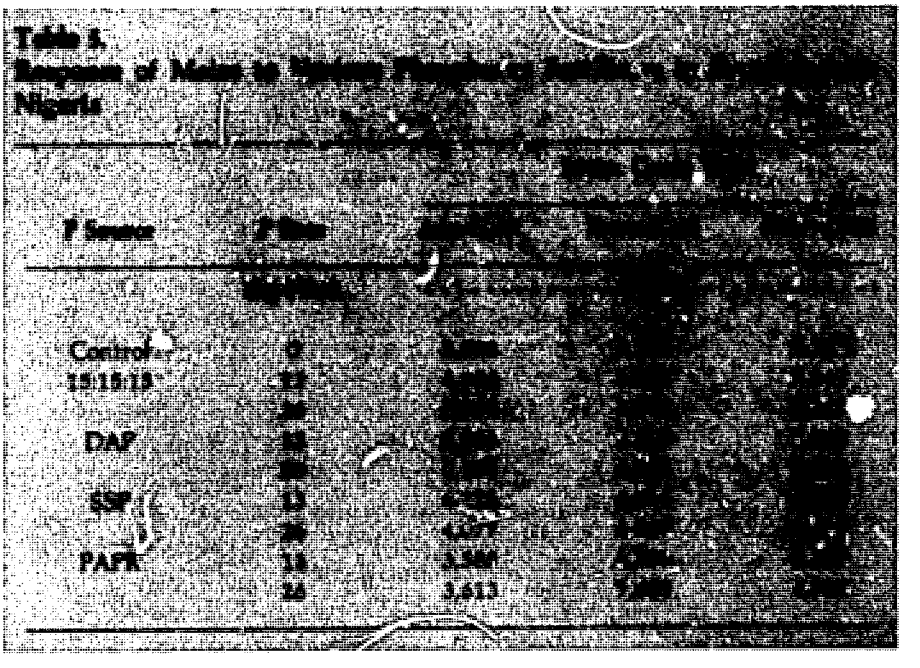


Table 5.
Response of Maize to Various Phosphorus Sources at Two Sites in Nigeria

P Source	P Rate	[illegible]	[illegible]
	kg/ha		
Control	0	[illegible]	[illegible]
15:15:15	13	[illegible]	[illegible]
	26	[illegible]	[illegible]
DAP	13	[illegible]	[illegible]
	26	[illegible]	[illegible]
SSP	13	[illegible]	[illegible]
	26	[illegible]	[illegible]
PAPR	13	[illegible]	[illegible]
	26	3,613	[illegible]

Field workers in Niger weed experimental plots.

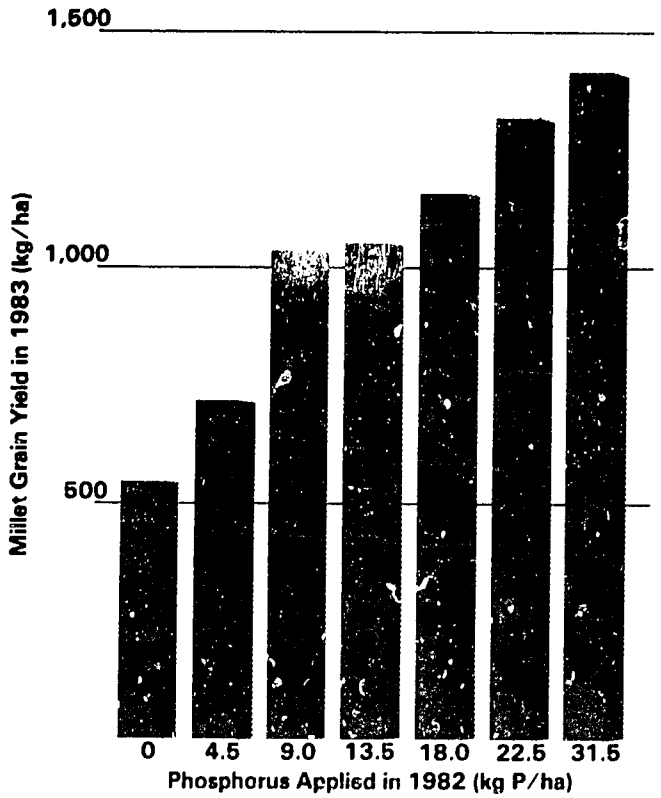


Figure 8. Effect of Single Superphosphate Applied in 1982 on Millet Yield in 1983 at Sadore, Niger.

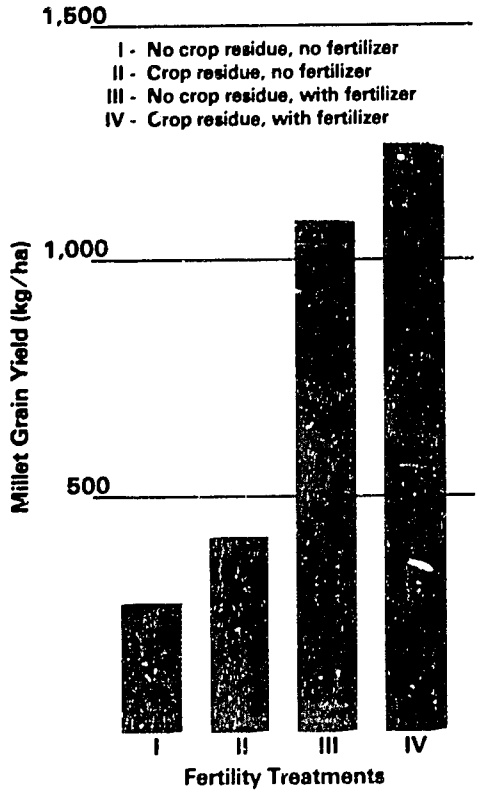


Figure 9. Influence of Crop Residues on Fertilizer Management at Sadore, Niger.

Field Research—Asia

An IFDC soil scientist worked with IRRI scientists at Los Banos, Philippines, during 1982 and 1983 investigating the efficiencies of phosphorus fertilizers applied to rice crops. They found that ground phosphate rock from Jordan and PAPR were potentially lower cost sources of fertilizer phosphorus than the more soluble fertilizers such as SSP, TSP, and DAP. A moderately reactive phosphate rock and phosphate rock acidulated with 15% or 30% of the sulfuric acid required to produce SSP were compared with SSP on two fairly acid soils during the 1983 dry season. All sources of phosphorus were broadcast and incorporated at rates of 0, 10, 20, 40, and 80 kg P/ha. Maximum yield responses were 28% and 82% above the control. SSP and PAPR (with 30% of the required sulfuric acid) gave similar yield responses, and both were more effective than the plain ground phosphate rock or the phosphate rock acidulated with only 15% of the sulfuric acid necessary to form SSP.

Socioeconomic Research

The social science field research in the Colombian phosphate project evaluates the acceptability of alternative phosphate sources by small farmers. The alternatives, phosphate rock and PAPR, may require changes in soil management, fertilizer handling, and method of application from methods that farmers traditionally use. Furthermore, for those farmers accustomed to complex fertilizers, using a single-nutrient fertilizer requires substantive changes in concepts as well as methods of fertilizer use.

The IFDC staff members stationed at CIAT conduct multidisciplinary evaluations of the promising phosphate fertilizers produced from indigenous Colombian deposits. The research has been therefore integrally involved with soil scientists in the selection of collaborating farmers and the design, establishment, monitoring, and evaluation of on-farm trials. A profile for each crop was compiled from detailed interviews with key informant farmers and a rapid appraisal survey of 100 farmers in the three research zones. Table 6 shows examples of farmers' fertilizer practices in each test crop. These data were used to define nonexperimental factors at the farmer's levels in the design of on-farm trials for each test crop. Methods of phosphate fertilizer application were determined by evaluating farmers' current methods of fertilizer placement. To monitor farmer management the IFDC sociologist kept a complete record of activities on experimental plots and farmers'

own plots for the test crops. Figure 10 illustrates the importance of fertilizer costs relative to other cash costs in the production of beans, one of the test crops.

Acceptability of New Fertilizers by Small Farmers

Evaluating the acceptability of IFDC's new fertilizers to the small farmer depends vitally on an understanding of how farmers themselves will assess the new technology. IFDC, with a supplementary grant from the Ford Foundation, developed a methodology for farmer assessment and compared this approach with other methods for on-farm testing of fertilizers. A sociologist initiated farmer assessment by conducting discussions with farmers about phosphate rock technology. A soil scientist incorporated into a new experimental design questions that farmers raised about the use of phosphate rock fertilizer. This design, called the "farmer design," was planted in 16 bean trials and 10 potato trials. By developing the farmer design through interviews with farmers, the research team could identify farmer objectives such as improving the return on cash investment in fertilizer; the importance of evaluating fertilizers relative to capital constraints; and adapting application methods to current practices. One important result of this methodology is that it will assist national programs to specify objectives for site-specific testing of fertilizers for small farmers.

The research team managed fertilizer trials with farmer designs in two different ways. One group of trials was research managed and farmer implemented: farmers received technical assistance and guidance in trial management from research or extension staff. Another group of trials was farmer managed and farmer implemented: farmers made their own decisions about management levels for the crop. Figure 11 shows the difference in bean yields obtained with PAPR treatments when farmers had different levels of decision making about the management of fertilizer trials. This finding illustrates how different methodologies for involving farmers in on-farm testing can influence results on the yield potential of new technology.

Direct farmer evaluation of results from these trials was also sought. For this purpose, yields were translated into terms farmers use to evaluate production. Farmers indicated the treatment that they considered most acceptable for future trial and adoption. Seventy percent of the farmers selected treatments including phosphate rock in preference over their usual practice. The results from this project show that methodology for farmer assessment can help to improve the efficiency of on-farm testing by enabling researchers to identify the relevant farmer objectives for evaluating acceptability, thus increasing probability for rapid adoption by farmers.

Table 6.
Fertilizer Practices Identified by Agro-Socioeconomic Profiles of Test Crops in Three Regions of Colombia

	Percent of Farmers
A. Bush Beans, Cauca Department	
Type of Fertilizer	
Chicken manure	76.1
Chicken manure + compound fertilizers	21.2
Farmyard manure + compound fertilizers	3.7
TOTAL	100.0
B. Upland Rice, Meta Department	
Type of Fertilizer	
Diammonium phosphate	29.0
Compound fertilizers	35.5
Phosphate rock or basic slag	3.5
Other	6.4
No fertilizer	25.8
TOTAL	100.0
C. Potatoes, Nariño Department	
Type of Fertilizer	
13-26-6	58.3
13-26-6 and 15-15-15 mixed	16.8
15-15-15	8.3
Phosphate rock with compound	8.3
15-15-15 and 10-20-10 mixed	8.3
TOTAL	100.0
D. Maize-Bean Intercrop, Nariño Department	
Type of Fertilizer	
13-26-6	30.0
15-15-15	15.0
10-30-10	7.0
None	48.0
TOTAL	100.0

Special Research and Development Projects

IFDC's laboratories, pilot plants, and agronomic evaluation facilities are often used to conduct special research and development projects for individual sponsors. During 1983 special studies were conducted on phosphate rocks from India, Malaysia, Chile, Niger, Senegal, Thailand, Uganda, the Philippines, and Jordan.

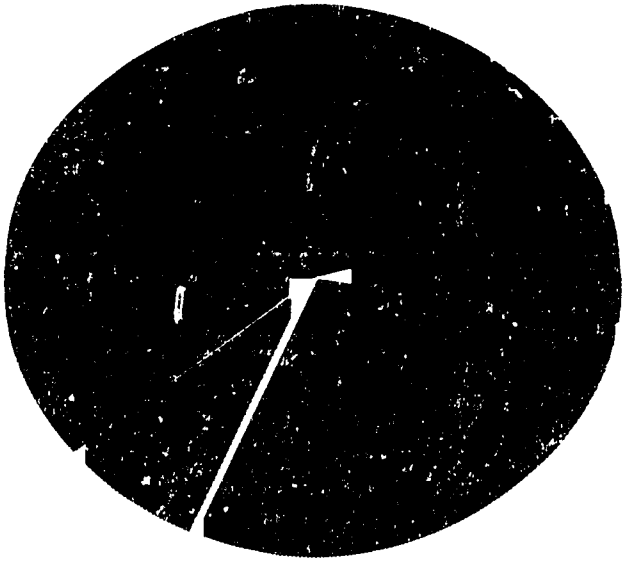


Figure 10. Distribution of Cost of Bean Production, Pescador, Colombia, 1982.

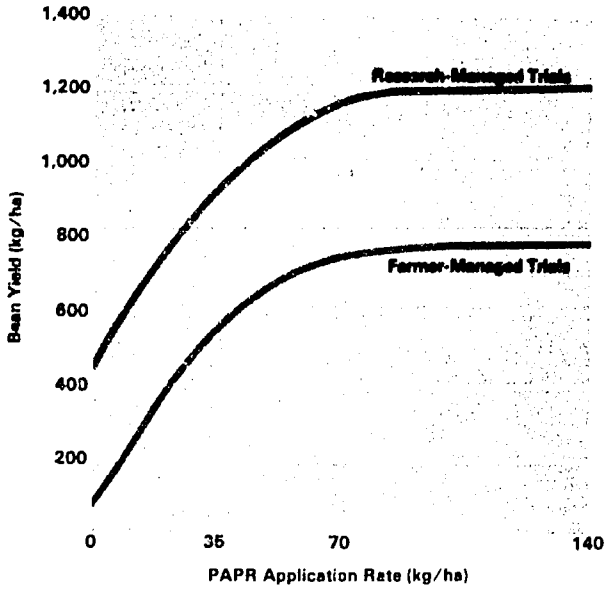
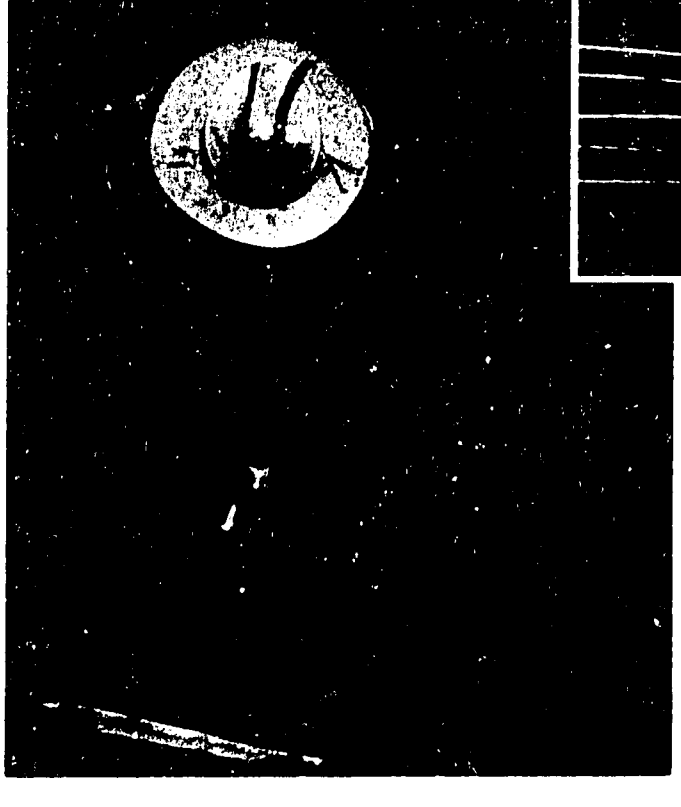


Figure 11. Yield Differences of Fertilizer Trials With Two Types of Farmer Participation, Bush Beans, Pescador, Colombia, 1982.

Dr. Jacqueline Ashby (right), IFDC Sociologist, interviews a Colombian farmer regarding his farming practices.



A Colombian farmer, collaborating with the IFDC Phosphate Project, applies fertilizer.

Granulation of Urea-Based Multinutrient Fertilizer for Malaysia

The Chemical Company of Malaysia Berhad requested that IFDC carry out tests to produce multinutrient fertilizer in continuous laboratory scale by a special process. IFDC fabricated a specially designed urea melter to supply low-biuret urea melt to the pugmill granulator. Three NPK formulations are being made; two contain magnesium and one is a 14-14-14 grade. Raw materials include urea, ground phosphate rock, potassium chloride, MAP, DAP, MgO, calcined magnesite, and calcined magnesium sulfate. Granules are conventional size, minus 3.35 plus 1.18 mm. The products will be subjected to selected physical properties evaluation.

Compaction Granulation of Multinutrient Fertilizer for Malaysia

A small project was initiated for Peladang Kimia Sendirian Berhad of Malaysia to evaluate NPK production by compaction using a variety of raw materials. Nitrogen sources are ammonium chloride, ammonium sulfate, ammonium nitrate, and urea. Magnesium is supplied by sulfate of potash magnesia. Ground phosphate rock and DAP are the phosphate sources. Potassium chloride and sulfate of potash magnesia supply potassium. Four formulas are to be made into conventional-sized granules. The company wants to evaluate the technical and economic feasibility of the compaction process.

Characterization/Beneficiation of Phosphate Rock From Chile

The Corporación de Fomento de la Producción of Chile is sponsoring a project for IFDC to carry out characterization and beneficiation studies on the newly discovered phosphate deposit called Bahia Inglesa. The company would like to produce phosphoric acid and TSP with this ore. The ore is medium-to-low grade (19% P_2O_5) and relatively high in silica, aluminum, and sodium, consisting of a weathered, quartz-feldspar sandstone cemented with apatite. It will require fine grinding for liberation of the apatite. Results of flotation tests yielded a concentrate containing 27% P_2O_5 and 11% SiO_2, from a starting feed containing 18.6% P_2O_5 and 25% SiO_2. Tests will be continued for improving the concentrate quality.

Characterization of Phosphate Rocks From Africa

As part of a project funded by IFAD two African rocks were characterized. They were Parc-W (Niger) and Matam (Senegal).

Parc-W—The Parc-W deposit is located along the Niger River, about 260 km south-southeast of Niamey. It is a relatively high grade ore containing about 28% P_2O_5. The main diluent is silica (about 25%); other impurities such as iron, aluminum, and magnesium occur at relatively low levels. Flotation can be used to upgrade the ore. Some exploratory tests produced a concentrate containing about 30% P_2O_5, with a P_2O_5 recovery of about 82%. The ore has a potential for use as a lower grade superphosphate or for PAPR.

Matam—The Matam deposit is located in the Senegal River Valley in eastern Senegal. It is relatively high grade (29.5% P_2O_5) with silica as a major diluent. The ore is high-to-medium in reactivity. A reduction in iron, aluminum, magnesium, and silica would be helpful if the ore were considered for phosphoric acid production. Some impurities might be reduced by desliming and flotation.

Characterization of Phosphate Rock From Thailand

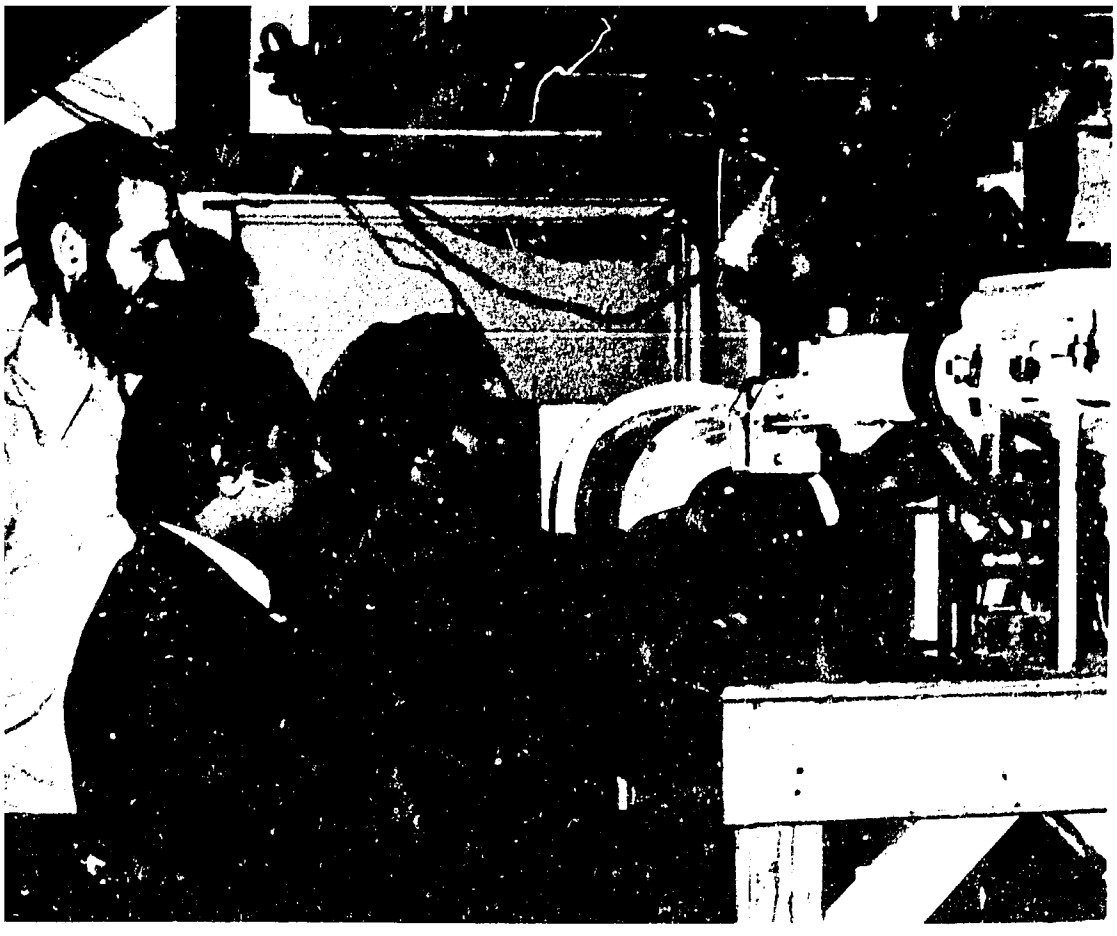
A sample of ore from the Lamphun area of Thailand was characterized for the National Fertilizer Corporation. The material is high grade (34.3% P_2O_5) with robertsite, calcite, and dolomite as major diluents. Impurities such as aluminum, magnesium, and iron are relatively low. The only questionable impurity that might affect chemical processing is manganese oxide (3.6%).

Studies of Uganda Phosphates

A substantial phosphate deposit of igneous origin is located in the Sukulu Hills region of Uganda. Previously it was mined and converted to SSP. There is renewed interest in reactivating the operation. IFDC is assisting through characterization of the ore and evaluation of factors affecting its use for SSP production. The concentrate is high grade (about 40% P_2O_5); iron is an impurity of concern in making SSP.

Studies of Mussoorie Rock From India

About 45 million tons of phosphate rock (average 18% P_2O_5) occurs in the Mussoorie area of India



Mr. Marshall Goode (left), IFDC Technical Aide; Mr. T. N. Jaggi, Managing Director of Pyrites, Phosphates, and Chemicals, Ltd. (PPCL); and Dr. Amitava H. Roy, IFDC Special Project Engineer, observe the operation of the bench-scale continuous granulation unit in IFDC's Pilot Plant.

and is presently being mined, finely ground, and sold for direct application fertilizer by Pyrites, Phosphates and Chemicals, Ltd. Dustiness of the product causes difficulty in transport and application and a low level of farmer acceptance where granular products are available and competitively priced. The company requested that IFDC evaluate the technical feasibility of the minigranulation and the single-step partial acidulation/granulation processes and determine the relative agronomic effectiveness of the various experimental products. IFDC also investigated an attrition scrubbing method using dilute acid to reduce calcite in the concentrate. The company stipulates that the partially acidulated product must contain at least 50% of its P_2O_5 in water-soluble form. Selected products were evaluated in IFDC greenhouse studies in 1983 and will be field tested in India in 1984. The company is considering installation of a pilot operation in India.

Studies of Use of Philippine Phosphate Rock

IFDC continued work to use phosphate rock from Bantigue, Leyte Island, the Philippines, in support of the new phosphate fertilizer complex for Philippines Phosphate Fertilizer Corporation (PHILPHOS). The work involved beneficiation of the ore and conversion of the concentrate to wet-process phosphoric acid. The ore has a P_2O_5 content of about 20% with major impurities consisting of iron, aluminum, and magnesium. Crushed ore was subjected to sizing and attrition scrubbing and yielded a concentrate of 29% P_2O_5 with an acceptable level of iron and aluminum, but unacceptable magnesium oxide content. No simple method was found to reduce the magnesium oxide level.

The Bantigue concentrate was tested in the IFDC bench-scale wet-process acid unit. Filtration rate and P_2O_5 recovery were relatively low. The concentrate tended to foam badly because of liberation of carbon dioxide.

Late in 1983 a sample of Kabulihan ore (29.4% P_2O_5) was received for testing in the wet-process acid unit and work is being continued.

PHILPHOS provided funding for IFDC to procure a complete laboratory-scale acidulation unit to be installed at PHILPHOS because they are implementing some research and development capability.

Preparation of Special Phosphate Products

IFDC prepared kilogram quantities of triammonium pyrophosphate and tetraammonium pyrophosphate for the Indian Atomic Energy Agency. Published preparatory procedures call for ammoniation of pyrophosphoric acid. The

procedure proved to be unsatisfactory, and recovery of the final products was very inefficient.

An alternate procedure proved satisfactory. A near-saturated solution of ammonium bifluoride was stirred with powdered calcium pyrophosphate. Calcium fluoride precipitated; a solution of diammonium pyrophosphate was left. The solution was decanted and filtered, and ammonium hydroxide was added to give the desired product.

Coating of Urea and Urea-Based Multinutrient Fertilizers

Petroliam Nasional Berhad (PETRONAS) continued to sponsor work on coating urea and urea-based NPK fertilizer with natural rubber latex. Representatives from PETRONAS assisted in the project. The purpose of coating is to retard dissolution of urea, thereby curbing nitrogen losses through ammonia volatilization, and to improve the physical quality of the product. Granular urea from a fluidized bed and granular urea-based NPK were used as substrates. PETRONAS supplied the rubber formulations. IFDC developed the techniques for the coating application in fluid bed and rotary drum processes on a batch laboratory scale. Urea release in water and soil was determined, and selected physical properties measurements were made. The purpose was to develop the technology of coating, evaluate coating parameters, and use the data to conceptualize the processes for a preliminary technical and economic evaluation.

Sulfur Research

During 1983 sulfur research focused on reactions of potential sources of sulfur when applied to soils under both flooded and upland conditions. The sulfur component of the major sulfur-containing fertilizers with potential for use in developing countries is either in the form of elemental sulfur or as a sulfate compound. The effectiveness of sulfur in the fertilizer may be determined, therefore, by a comparison of the reactions of those two forms under varied conditions. Both forms exhibit properties that may be considered as either an advantage or a disadvantage. Elemental sulfur, for example, is a high-analysis material but is difficult to work with. Its availability to plants is delayed because it must first be oxidized to the sulfate form; however, this also results in a greater residual value. The selection of appropriate sulfur-containing fertilizers must consider these and other basic reactions, which are under investigation at IFDC.

PETRONAS and IFDC personnel observe the rubber coating of urea in a rotary drum at Headquarters.

Reactions of Sulfur-Containing Fertilizers in Flooded Soils

Elemental sulfur, the most concentrated form of sulfur, perhaps is the most economical choice to be added to the high-analysis multinutrient fertilizers for developing countries. Since plants can take up sulfur only in the oxidized sulfate form, elemental sulfur has been generally considered unsuitable for flooded rice because of reduced soil conditions. However, recent studies under greenhouse and field conditions in Indonesia indicate that elemental sulfur was as good as gypsum or ammonium sulfate in increasing rice yield when surface applied at transplanting. Research is needed to study the mechanisms of sulfur oxidation in flooded soils.

IFDC conducted a soil and incubation study to investigate whether sulfur oxidation could occur in the top thin oxidized layer of a flooded soil under greenhouse conditions. A Crowley silt loam soil (Typic Albaqualf) that had been preflooded was used. During a 10-week incubation period, it was found that a significant amount of sulfur oxidation occurred during 2-5 weeks when powdered elemental sulfur was surface applied. Later, sulfur immobilization, presumably by algae, exceeded the rate of sulfur oxidation so that a decrease in oxidized sulfate was observed after 7 weeks of incubation. Because of the high redox potential (+385 mV) on the surface layer, it is unlikely that reduction of sulfate to hydrogen sulfide was responsible for the decrease in the amounts of sulfate in the flooded soil after prolonged incubation. When the elemental sulfur was totally mixed with the soil, no sulfur oxidation was observed. Similarly, no significant sulfur oxidation was observed when SCU granules were placed on the soil surface. This suggests that SCU may be a relatively poor source of sulfur for flooded rice.

Reactions of Sulfur-Containing Fertilizers in Upland Soils

In addition to studies on flooded soils, research was conducted at IFDC Headquarters to measure the effect of including either elemental sulfur or gypsum with nitrogen, phosphorus, and potassium fertilizer mixes applied to sulfur-deficient upland soil. In experiments with maize grown under growth chamber and greenhouse conditions, nitrogen, phosphorus, and potassium were supplied as urea, TSP, and potassium chloride alone and in combination. The effectiveness of each combination was measured without added sulfur as well as with application of elemental sulfur or gypsum, which contained 18.6% sulfur. In each case the fate of the applied sulfur was followed not only with regard to plant uptake but also with respect to susceptibility to nutrient loss through leaching.

While it is already recognized that phosphate and sulfate ions compete for sorption sites in the soil and therefore sulfate is more susceptible to leaching when phosphate is applied, it is important to quantify the effect of the competing ions on sulfate loss to determine the most effective means of including sulfur as a component of multinutrient fertilizers. For example, the loss of sulfate can be greatly increased by adding TSP alone without the application of sulfur-containing fertilizer (Figure 12). In this case, sulfate loss increased by 260% by application of TSP alone. The loss of sulfate after the application of gypsum was 32% higher than was measured when elemental sulfur was applied alone.

Figure 13 illustrates the interaction between TSP and either elemental sulfur or gypsum with respect to susceptibility to leaching loss when the elements are supplied either alone or in combination. The sulfate recovered in the leachate when TSP and gypsum were applied together was greater than the losses when the source of sulfur was elemental sulfur. Since no difference in maize yields was observed between the combinations of TSP plus elemental sulfur and TSP plus gypsum, the differences in leaching loss suggest that the losses of sulfate from gypsum occurred before the rooting systems of the maize plants were developed sufficiently to use the sulfate. This resulted in early leaching losses that were not encountered with elemental sulfur because the transformation of sulfur to sulfate through oxidation was delayed until the rooting system had become more fully developed.

These experiments suggest that the use of elemental sulfur in compound fertilizers can improve the efficiency of use by plants and that additional research is warranted to develop safe and economical means of incorporating elemental sulfur into fertilizers in a form that is available to the plant.

Potassium Research

During 1983 IFDC conducted a major study that analyzed the role of potassium fertilizers in

tropical agriculture. This study was also sponsored by the International Potash Institute and the Potash and Phosphate Institute (PPI).

Specific goals of the study were to:

1. Evaluate the potential for potassium fertilizer use as affected by the sociodemographic factors of developing countries.
2. Identify the constraints to increased use of potassium fertilizers and to suggest how they may be overcome.

Developing countries have greatly increased their use of fertilizers in the past decade and now account for only about 40% of the nitrogen, 30% of phosphate, but only 10% of the potash used in the world.

In 1981/82 IFDC surveyed 26 countries in the tropics and subtropics concerning their current use of potassium fertilizers. The survey was made by using questionnaires and personally interviewing research workers and specialists familiar with fertilizer use and soil fertility in each country.

Results of the survey showed that an estimated one-fourth of the soils in these regions are deficient in potassium. (In some areas as much as 70% of the land is deficient.) Crop response to applications of potassium fertilizers varied widely with the crop and the type of cultivar used. But in nearly all cases where there was a potassium deficiency, the yield response was great enough to justify the application.

At harvest time all crops contain very large amounts of potash. Depending on the crop and the material taken from the field, this potash may be almost totally removed or, particularly in the case of mechanically harvested grain, left almost entirely in the field. A critical factor in reducing potash loss from the farms is therefore the efficiency with which the farmer recycles crop residues.

Agronomic factors that increase the need for potassium fertilizers are (1) the introduction of high-yielding cultivars, (2) increases in cropping intensity, that is, growing two or three crops each year, (3) use of new lands for cash or export crops, (4) use of other inputs such as irrigation water and pesticides to increase the yields, and (5) use of potassium to increase the crop's tolerance to saline conditions and to drought.

The present constraints to the use of potassium fertilizers appear to be (1) a lack of knowledge by the farmer, the fertilizer dealer, the demonstration agent, and other government officials about the need for such fertilizers and the benefits derived from them; (2) a lack of research on maximum yields and the role these fertilizers would play; (3) unfavorable crop-fertilizer price ratios; and (4) the limited availability of potassium fertilizers in the marketplace. Specific recommendations for alleviating constraints to the use of potassium fertilizer include the following:

1. Governments should increase research and extension activities designed to identify the need for and, where appropriate, promote the use of potassium fertilizers.

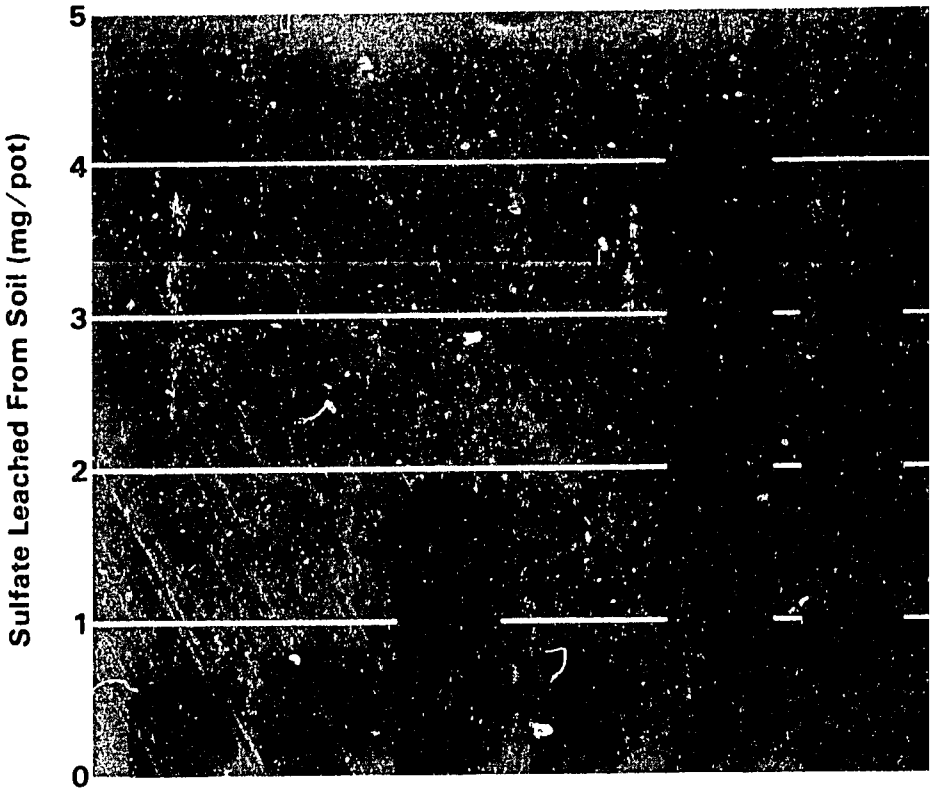


Figure 12. Loss of Sulfate by Leaching as Influenced by Type of Fertilizer Applied.

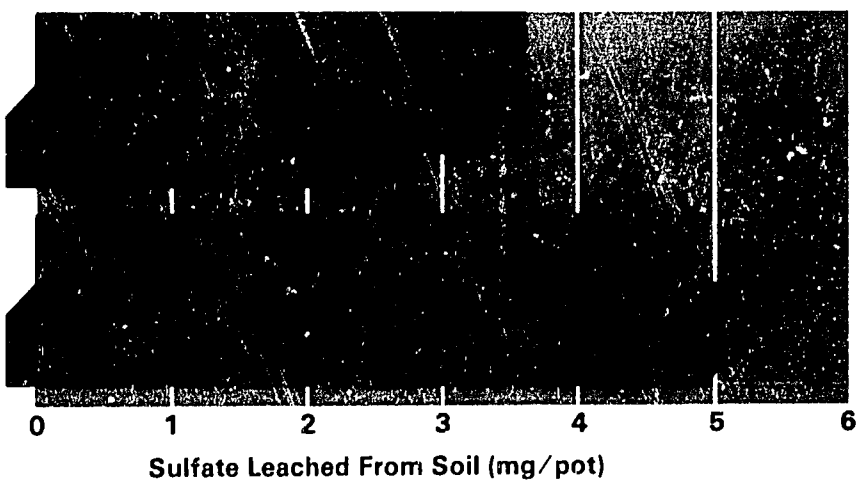


Figure 13. Loss of Sulfate by Leaching as Influenced by Interactions Between TSP, Elemental Sulfur, and Gypsum.

2. Where governments control the availability and price of fertilizers, efforts should be intensified to ensure that farmers have the same physical and economic access to potassium fertilizers as is generally extended to nitrogen and phosphate fertilizers.

The following general recommendations were advanced as influencing potassium demand in developing countries:

1. Create an effective market structure to dispose of agricultural produce.
2. Avoid establishment of cheap food policies that are maintained at the farmers' expense by setting output prices at low levels.
3. Subsidize the cost of all fertilizers whenever low prices must be maintained.
4. Teach farmers how to improve their crop management and water control practices.
5. Give strong support to the agricultural sector with emphasis on strengthening the research and extension services.
6. Establish a national fertilizer program that takes into account all fertilizers necessary to sustain an efficient agriculture.
7. Intensify research on achievable maximum crop yields.

Economics Research

The profitability of fertilizer use is extremely important. Unless and until a farmer is assured of receiving reasonable returns for his investment for fertilizer he will not use it. This profitability and the economics of fertilizer use can be modified through improvements in fertilizer use efficiency and favorable fertilizer policies. The IFDC Economics Program deals with analyzing (1) constraints to fertilizer use at the farm level, (2) the economic evaluation of modified fertilizer, and (3) the economic evaluation of fertilizer-related government policies with the objective of developing guidelines for policymakers of developing countries.

Farm-Level Economics

Fertilizer Use and Agricultural Production

IFDC economists, in collaboration with the Rashtriya Chemicals and Fertilizers Limited (RCF), carried out an intensive study of fertilizer use in the state of Maharashtra in western India. Farming in this state primarily depends upon rainfall that is uneven and insufficient. Only 12% of the cropped area is irrigated, and crop production is subject to the uncertainties of the weather. The study covered different farming aspects on 1,800 farms at 18 locations in the state. The data concerning input use, crop production practices, crop yields, and soil analysis were collected for the crop year 1981/82 by an in-depth farm survey covering all farm plots.

Dominant crops in the state of Maharashtra are the upland crops of sorghum, pearl millet, groundnuts, cotton, and sugarcane. The overall objectives of the study were to identify various types of constraints to crop production and efficient fertilizer use and to develop policy implications of the survey findings for RCF, other fertilizer organizations, and the government for efficient fertilizer marketing and use for increasing food production.

The results of the study indicate that the average operational farm size for the sample areas was 2.91 ha, which is about 46% larger than the Indian average of about 2 ha. About 54% of the farms are smaller than 2 ha, 12% smaller than 0.5 ha, and 15.5% are larger than 5 ha.

Survey results indicate that the fertilizer market in Maharashtra is quite complex because several fertilizer products including mixtures are available. This complicates farmers' choice and increases the need for knowledge to enable them to select proper products and to use them efficiently. Most farmers in the study areas were, however, aware of fertilizer and a large majority of them use it. Yet, however, only 56% of the cropped areas during summer (wet season) and 30% during winter (dry season) were fertilized. Many farmers did not have a clear knowledge of fertilizer use recommendations.

Average fertilizer use per hectare of cropped area during summer and winter, respectively, was 39 kg and 12 kg. However, since substantial cropped areas were not fertilized, the average nutrient use per hectare on the fertilized cropped areas during summer and winter was 143 kg and 81 kg of NPK, respectively.

Sugarcane (28%), cotton (24%), sorghum (21%), and wheat (9%) are the crops on which most of the fertilizer was used in sample areas. Urea, NPK compounds such as Suphala 20:20:0 and Suphala 15:15:15, and mixture 18:18:10 were the major fertilizer products used. As a source of nitrogen, urea was the major source followed by Suphala and the mixture 18:18:10. Phosphorus was usually supplied by Suphala and mixture 18:18:10 and potash by Suphala 15:15:15 and mixture 18:18:10. Most farmers supplemented fertilizer with farm manures, and

most of it was applied during the summer season.

Results relating to fertilizer availability and farmers' purchase behavior indicate that the average distance between farms and fertilizer depots is about 9 km and that, on an average, each farmer in a given season buys fertilizer 1.3 times, visits the fertilizer depots 1.8 times, spends about 4 hours per visit. These transaction costs represent 4.7% of the fertilizer purchase price. In Maharashtra, the cooperatives supply a substantial proportion of fertilizers at the retail level, and they are the main source of credit.

Irrigation, the use of high-yielding varieties (HYVs), labor, proper drainage, and fertilizer-to-crop price ratios were shown to be important factors that influenced fertilizer use during summer as well as winter seasons. The impact of irrigation was particularly strong in the case of sorghum, wheat, rice, groundnuts, and sugarcane crops. The estimates show that a 10% increase in the proportion of irrigated cropland would, when all other variables are held constant, increase fertilizer use by 14.6% for sorghum, 10.2% for wheat, 19.5% for paddy, and 12.7% for groundnuts. The impact of HYVs was strong for sorghum and cotton crops. When other factors were held constant, the use of HYVs increased fertilizer use by 21 kg of NPK/ha for sorghum and 33 kg for cotton. The effect of changes in fertilizer-to-crop price ratios on fertilizer use was strong in the case of cotton, sugarcane, and sorghum crops. On an average for these crops, a 10% increase in the price ratio, when other factors are held constant, decreased fertilizer use by 9.4%. Fertilizer use in the case of wheat, paddy, and groundnut crops was much less sensitive to price changes.

The study's results showed that broadcasting by hand and drilling were the two most commonly used methods of fertilizer application. As an average for the study areas, per-hectare input of labor for applying fertilizer was 14 hours for HYVs of paddy, 23 hours for summer sorghum, 34 hours for HYVs of pearl millet, 164 hours for HYVs of cotton, 78 hours for sugarcane, and 29 hours for wheat. These quantities of labor were 2.0%, 4.1%, 6.3%, 15.9%, 4.7%, and 4.4%, respectively, of the total per-hectare labor required to produce these crops.

Results of this study also indicate that irrigated crops of HYVs of rice, winter sorghum, and wheat produced net benefits of fertilizer use almost equivalent to those for the sugarcane crop. When the use of HYVs and irrigation was at sample average levels, the net benefit of fertilizer use was Rs 494/ha. However, for an irrigated crop of HYVs the benefit was Rs 1,137/ha. The positive influence of HYVs and irrigation on the benefits of fertilizer use is clearly shown by these results.

Policy Research

Research on fertilizer policies at IFDC is designed to analyze the economic consequences and generate information appropriate for formulating public policies related to research, production, marketing, and use of fertilizers in developing countries of Asia, Africa, and Latin America. During 1983 IFDC's policy research focused on the situation in Bangladesh.

Price Policy in Bangladesh

One of the most common government involvements in the fertilizer sector in developing countries is price control at the retail level. Such a policy tends to distort market signals and misallocate fertilizer. Most countries are afraid that prices will skyrocket if they are decontrolled.

The retail fertilizer prices were controlled in Bangladesh. However, effective April 1, 1982, prices were decontrolled in Chittagong division. The price deregulation was extended nationwide effective April 1, 1983. The price policy research in Bangladesh falls into two categories. These are (1) framework for monitoring fertilizer prices and (2) economic impact of fertilizer price decontrol.

Framework for Monitoring Fertilizer Prices—Since 1978 the Bangladesh Government has been introducing major reforms in the fertilizer marketing system. In October 1980, the Bangladesh Agricultural Development Corporation (BADC) and IFDC initiated a farmer fertilizer price survey. The primary purpose of this study, carried out as an activity under the IFDC/BADC project (see National Programs, Bangladesh), was twofold: to make recommendations to improve the ongoing fertilizer price survey and to develop a framework for economic analysis.

Detailed guidelines have been developed to collect, on a regular basis, fertilizer prices through farm-level fertilizer price surveys, to analyze the price data by computer and generate appropriate price indicators, and to report various price indicators in formats useful for policymakers.

The proposed system would generate monthly comparative fertilizer price indicators for several market locations, for different market categories,

and for all the districts in the country. Consequently, the monitoring system would provide "early warning signals" to policymakers for any abnormal price behavior so that appropriate and timely corrective actions might be taken by the government.

Economic Impact of Fertilizer Price Decontrol—Farm-level fertilizer price data have been collected for several months from both regulated and deregulated fertilizer markets. This is rather a unique experiment in price policy in which the whole country has been divided into regulated and deregulated market areas. The primary purpose of this study is to determine the economic impact of price deregulation on fertilizer prices and fertilizer availability. The results will be useful for fertilizer price policy formulation not only in Bangladesh but also in other developing countries.

The monthly price data that form the basis of this study deal with three popular fertilizers, seven fertilizer market categories, 10 districts in four divisions, and a period of 20 months. In all, over 9,000 farmers have been interviewed over this period. The time period deals with three fertilizer price policy regimes: (1) prices were completely regulated, (2) prices were regulated in three divisions and deregulated in one division, and (3) prices were completely deregulated. The detailed economic analysis is still being conducted. However, preliminary results indicate the following:

1. The actual fertilizer prices paid by farmers generally did not match the prices fixed by the government in regulated market areas.
2. The retail fertilizer prices were slightly higher in deregulated than in regulated fertilizer markets, especially in remote market categories. However, there is some evidence that fertilizer availability did improve in deregulated areas.
3. The price variability in deregulated fertilizer markets was slightly higher than in the regulated market categories; thus, a larger fertilizer price uncertainty was created.

Sulfur Strategy Study

This study, entitled "Fertilizer Sulfur and Food Production: Research and Policy Implications for Tropical Countries," deals with the economic importance of sulfur in the fertilizer industry, food production, and the agricultural sector in the tropical countries of Asia, Africa, and Latin America. The study provides guidelines for future directions in fertilizer sulfur research and public policy. Even though the focus is on the tropical countries, the study is expected to be useful for fertilizer researchers, extension agents, manufacturers, distributors, planners, and policymakers around the world.

One of the main objectives of the study is to analyze sulfur deficiency as a constraint to food production by examining the nature, causes, magnitude, and location of sulfur deficiency and crop response to applied fertilizer sulfur. Another objective is to estimate the aggregate fertilizer sulfur requirements, supplies, and implied gaps between the two in selected tropical countries and regions from 1960 to 2000. A third is to examine past performance, the current economic situation, and future outlook with respect to sulfur demand, supply, prices, resources, and trade. The study also evaluates alternative fertilizer sulfur strategies in the context of indigenous sulfur resources and analyzes the implications for fertilizer sulfur research and public policy.

Sulfur deficiency, inherent or induced, is widespread and growing. This adversely affects input productivity, crop production, and human nutrition. Serious sulfur deficiency problems have been identified in 46 tropical countries, including 10 in Asia, 21 in Africa, and 15 in Latin America. Even though these problems appear to be localized, sulfur deficiency may become a serious problem if no corrections are taken. Intensification of agriculture, use of improved crop varieties, an increasing use of sulfur-free fertilizers, phosphating, liming, and leaching, especially in coarse-textured soils, are further aggravating the sulfur problem.

The total world sulfur requirements in the year 2000 are estimated to be approximately 50 million mt of sulfur as crop nutrient and 65 million mt of sulfur for the fertilizer industry. Only a part of the sulfur requirements as nutrients is supplied by sulfur-containing fertilizers. The projected fertilizer sulfur gaps are estimated to be large and widening. Unless something is done to bridge these gaps, national and international efforts to accelerate food production will be seriously handicapped.

Since most of the tropical countries are net importers of sulfur, alternative sulfur supply strategies must emphasize the use of indigenous sources such as gypsum, phosphogypsum, and pyrites. Even though a large share of sulfur is used in the fertilizer industry, mainly to manufacture phosphate fertilizers, most of it is discarded as byproduct phosphogypsum. Use of phosphogypsum and fortification of popular fertilizers with sulfur deserve high priority.

Market Situation and Outlook

Fertilizer Price Analysis

During 1983 IFDC continued to collect and analyze two types of price data. These data include:

1. Monthly farm-level prices for principal fertilizer products and crops in African, Asian, and Latin American countries.
2. Weekly international spot prices for key fertilizer products and materials.

Data collection from in-country sources began in late 1979 and has been continued on a monthly basis for about 30 countries. Prices are in local currency and are converted to a standard unit (US $/ton). This information is maintained on a computer data base and is available for determining fertilizer-crop price relationships as needed in various research projects. Farm-level prices, which can be analyzed to determine changing trends and farmers' incentives to use fertilizers within and among countries, are of value to policymakers in developing countries. This information is also useful in analyzing various policy proposals to determine why some countries use higher fertilizer application rates than do other countries.

Regional Supply/Demand Statistics

In recent years IFDC has had a large number of requests for fertilizer product statistics. As a result of this, IFDC has compiled as much data as possible on product types, rather than on a nutrient basis. This has involved obtaining information directly from correspondents in developing countries. At the present time IFDC has product information on approximately 60 developing countries. The countries supplying these statistics use about 85% of the fertilizer consumed in developing countries. Three regional reports were prepared in 1983, which included these data as well as information on regional trends. These reports include the "Africa Fertilizer Situation," "Asia Fertilizer Situation," and "Latin America Fertilizer Situation." These reports will be updated approximately every 6 months with the latest product information available.

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"The final test of IFDC's impact is the degree to which the Center's research and development is incorporated into national fertilizer-sector programs. Therefore, establishing national-level programs will continue to be a major goal of IFDC."

Dr. Dennis H. Parish, Director
Outreach Division, IFDC

National Programs

IFDC holds to the philosophy that the solutions to Third World problems lie with the people themselves. The Center is dedicated to helping them help themselves and continues to look for ways of establishing a greater presence in these regions.

One means of achieving this end is to encourage the establishment of national fertilizer programs in developing countries. Through this means IFDC's scientists can work directly with national scientists in solving their countries' fertilizer-related food production problems.

IFDC now has national programs established in Bangladesh, Indonesia, and Mali. The Bangladesh program underwent further expansion during 1983. The national program in Indonesia is conducted by three working groups and focuses on improving nitrogen fertilizer efficiency. In assisting Mali with the best use of its indigenous phosphate rock, the national program in Mali branched out onto farmers' fields during 1983.

Bangladesh

The year 1983 saw a further expansion of IFDC's fertilizer marketing and distribution technical assistance activities in Bangladesh. Inaugurated in 1979 as part of USAID's Fertilizer Distribution Improvement Program, the IFDC program assists BADC in increasing the efficiency of its fertilizer delivery system. Fertilizer is a key input to increase food crop output to government-planned self-sufficiency levels on a timely basis in a cost-effective manner. Focused mainly on improving the operation of the fertilizer marketing and distribution system through the day-to-day activities of three IFDC resident consultants posted at BADC Headquarters in Dhaka, the program includes special projects designed to ease individual constraints to fertilizer marketing and use efficiency. The program, supported by short-term consultants from IFDC Headquarters' staff and outside sources, also provides training in fertilizer production, marketing, and use.

Fertilizer Distribution

Notable progress was made during 1983 in accomplishing the fertilizer distribution activities initiated earlier. The fertilizer stock control and accounting system developed for and in conjunction with BADC management personnel was put into full effect. Instructional sessions were held at district offices and godowns and meetings with personnel assigned to a newly created headquarters group responsible for preparing centrally consolidated stock reports used to monitor fertilizer availability on a national basis.

To ensure timely delivery to fertilizer sales centers, the distribution consultant initiated the development of a centralized fertilizer movement control system. This system will aid in planning and monitoring stock requirements and movements for each principal distribution point on the basis of sales targets, warehouse inventories, in-transit stocks, and stock replenishment leadtimes.

The warehouse management system, including the godown operating and maintenance manual developed earlier, received continued study by BADC management, which agreed to its trial implementation at a recently constructed large godown.

Monitoring of the least-cost transport system indicated close compliance to the route and mode-wise program developed to improve transport efficiency and to lower costs. The consultant prepared master movement plans and routing guides for the 1982/83 and 1983/84 fertilizer years.

Examination of the status of the earlier proposed bulk import program indicated that about 70% of imports are in bulk form; this results in greatly reduced costs for imported fertilizers.

IFDC assisted USAID and BADC in planning improvements for the fertilizer marketing and

distribution system proposed for implementation in the planned second phase of the USAID fertilizer distribution improvement project.

Fertilizer Marketing

Improvements in the operation and management of the marketing function were continued under the leadership of the marketing resident consultant. IFDC staff held training sessions in marketing plan development and use for BADC staff members. A full-scale annual marketing plan for the 1983/84 fertilizer year was prepared. The annual marketing plan identifies objectives, policies, strategies, and tactics for carrying out the marketing functions required to achieve defined sales goals within a framework of expanded availability, sales, and efficient fertilizer use at the farm level.

IFDC assisted BADC in the preparation of forecasts and monitoring of annual sales and supplies from domestic factories and imports. A procurement committee with representation from BADC and Bangladesh Chemical Industries Corporation, the main domestic fertilizer producer, was established to coordinate local production and movement with demand.

The monthly farmer survey to monitor fertilizer availability, farmer prices, credit usage, application rates, and farmer information sources as well as crop prices received by farmers was continued and expanded. Fertilizer sales, which in 1982/83 increased about 15% over those in the preceding year, continued to gain momentum in the last half of 1983. Fertilizer prices rose immediately after decontrol but soon after declined to levels slightly above those before price decontrol. Farmer paddy prices rose moderately while wheat prices declined. Fertilizer availability showed general improvement, but credit usage remained very low. Plans were developed for expanding and computerizing the farmer survey in 1984.

After several modifications, a fertilizer wholesaler in-kind credit program, with loans secured by bank guarantees, was launched. About 150 fertilizer wholesalers have been approved for participation. Meetings were held between bank officers and BADC managers to exchange information about the role of credit in fertilizer sales and to solicit cooperation in promoting the use of credit by dealers.

IFDC continued to assist BADC staff in preparing and publishing the widely used monthly BADC Fertilizer Newsletter, which serves as a timely and authoritative source of fertilizer supply and sales statistics.

Dealer Development and Training

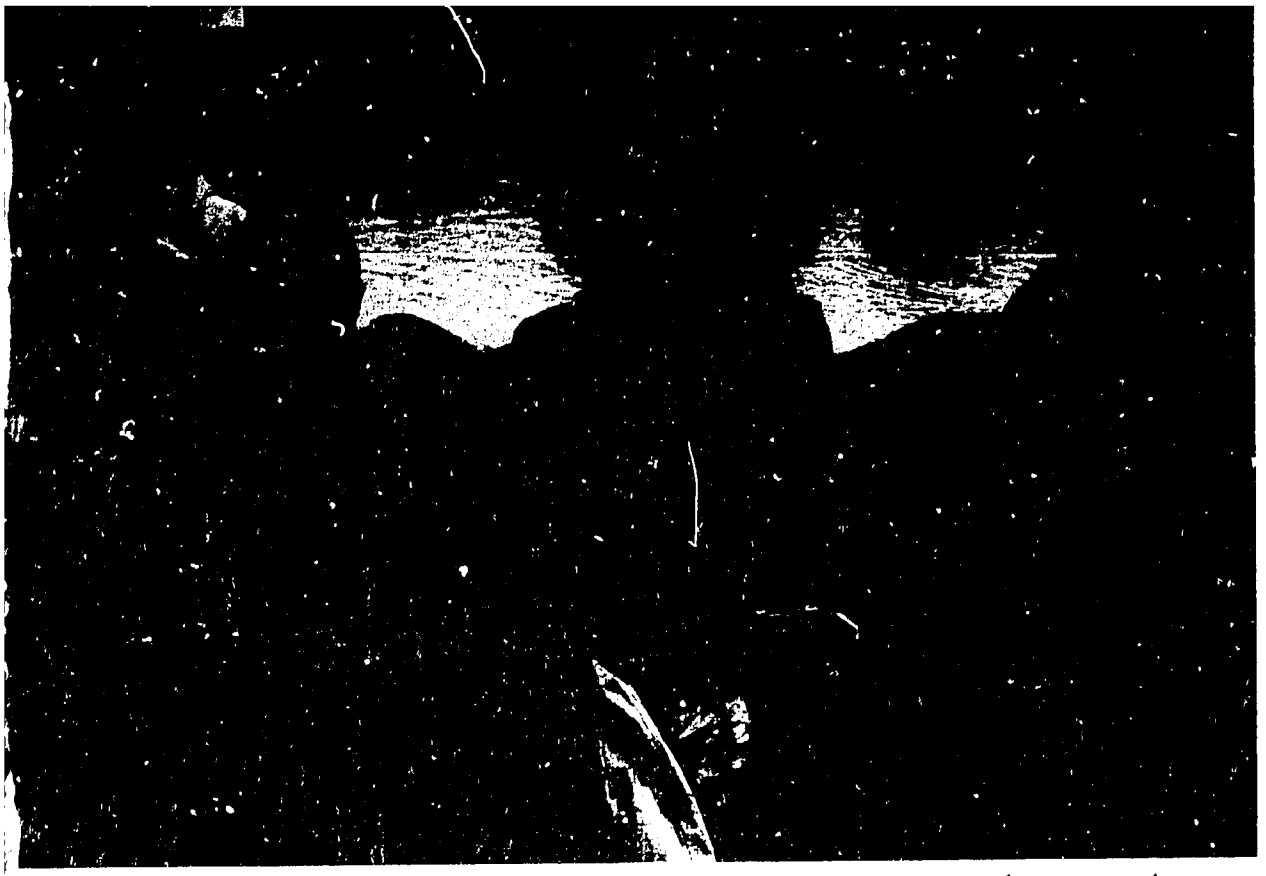
A major training program was developed to teach the private dealers how to promote expanded and proper use of fertilizers.

A cadre of BADC dealer trainers was developed through repetitive "train the trainer" programs, and training officers were appointed for each district. Dealer training and sales promotion aids were prepared for use in the program. These aids included a dealer manual, fertilizer recommendations, soil maps, fertilizer use brochures and flip charts, rice and wheat production pamphlets, fertilizer information slides, and brochures on zinc and sulfur. Dealer interest in this program remains high; about 7,000 dealers participated in these on-going dealer training programs.

Development of the dealer system and efforts to improve dealer performance were continued through regularly scheduled dealer meetings at which BADC sales policies and practices were discussed and technical information exchanged. Over 4,000 dealers participated in such meetings in 1983.

Dealer-oriented sales promotion aids designed to stimulate fertilizer use were produced and widely distributed to satisfy strong dealer demand for such sales aids. These included wall posters on nitrogen, phosphate, potash, zinc, sulfur, organic matter, and diammonium phosphate and brochures on rice, wheat, and vegetable production. A film, "Making the Most of a Miracle," produced by The Fertilizer Institute on the role of plant nutrients in plant growth, was dubbed into Bengali and found wide and enthusiastic use in Bangladesh.

AID, BADC, and IFDC officials review the Bangladesh program during a tripartite meeting in Dhaka.



Bangladesh children like these should benefit from IFDC's involvement in their country's agricultural sector.

Special Projects

Procurement Practices

A 3-month consultancy to assist BADC in implementing fertilizer procurement procedures designed to improve availability and lower costs was conducted during 1983.

Agronomic Services

The agronomic services consultancy intended to study fertilizer use efficiency and lead to improved fertilizer recommendations was continued. Under the Coordinated Fertilizer Efficiency Project, carried out in association with the Bangladesh Agricultural Research Council (BARC) and its member institutions, 23 nitrogen management experiments were carried out on a series of major soils during three successive rice-growing seasons. In tests made during the fall and winter months at a 60 kg N/ha rate, significant increases in rice yield (35%-70%) were recorded for deep hand-placed urea supergranules as compared with the conventional split broadcast regimen.

Byproduct Gypsum

At the request of the Ministry of Agriculture and BADC, an IFDC staff member made a study of ways to use byproduct gypsum, produced at the Chittagong TSP plant, as a source of vitally needed agricultural sulfur. The recommendations of the study were implemented, and greatly increased quantities of byproduct gypsum are now being used for that purpose.

Fertilizer Equity Study

This research, funded by USAID, was jointly carried out by IFDC and BARC. The main purpose of the investigation was to develop appropriate farm-level data on (1) the constraints to and potential for increasing food production in Bangladesh and (2) the distribution of the gains from fertilizer use among various farm groups.

The report entitled *Agricultural Production, Fertilizer Use, and Equity Considerations—Results and Analysis of Farm Survey Data, 1980/82, Bangladesh*, prepared in 1983, is the third in a series and covers five crop seasons—1980/81 Boro to 1982 Aus.

The results of this study indicate the potential for increasing food and agricultural production in Bangladesh by expanding the use of irrigation, HYVs, and chemical fertilizers. They also show that the highest level of fertilizer use in terms of total crop areas fertilized, as well as percentage of crop areas fertilized, was found during the Aman season followed by the Aus and Boro

Bangladesh workers load phosphogypsum at the Chittagong factory.

seasons. The per-acre use, however, was the highest during the Boro season (48.15 kg) followed by the Aman (33.22 kg) and Aus (29.11 kg) seasons. On an average for the five seasons (1980/81 Boro to 1982 Aus), about 65% of the farmers used fertilizer. However, the percentage of farmers using fertilizer varied greatly across sample locations during each of the five seasons. In some locations almost every sampled farmer used fertilizer, whereas in others the proportion of farmers using fertilizer was as low as 3%-4% during some seasons. The average benefits of fertilizer use per hectare of cropped land were considerably larger during the Boro season than during the Aus and Aman seasons. These benefits were not significantly different among various farm-size groups, but they were substantially influenced by weather conditions. Results also show that the use of fertilizer on paddy increased the employment of labor by about 32 workdays per hectare and that this effect was even higher on farms smaller than 1.01 ha.

Personnel Training

IFDC provided training to personnel from BADC and other government organizations through their participation in IFDC Headquarters and regional training programs on fertilizer production, marketing, and use. The BADC Manager of Dealer Development and Training received individual training at IFDC and other U.S. locations on the role of dealers in fertilizer marketing.

A 2-week in-country fertilizer marketing management training program was conducted in Dhaka by IFDC resident consultants and Headquarters staff members for 32 BADC marketing officers.

As part of the Agronomic Services Consultancy, a 2-week in-country training program on fertilizer efficiency research techniques was conducted for 34 scientists and specialists from BARC and its affiliated research institutions, universities, and extension departments.

Indonesia

IFDC and the Agency for Agricultural Research and Development have collaborated since 1982 on a joint project to improve fertilizer efficiency on food crops. This project, funded primarily by the Australian Development Assistance Bureau, includes three resident consultants located in the Centre for Soils Research (CSR) that through CSR advise and assist three working groups (upland, lowland, and socioeconomic) on activities related to the objectives of the project. The working groups have focused on finding ways to improve nitrogen efficiency in flooded rice, identifying

Mr. Matt Shepherdson of ADAB (left); Dr. Paul J. Stangel, IFDC's Deputy Managing Director; and Dr. Sudjadi of AARD inspect trials of fertilizer cropping systems in South Sumatra.

An Indonesian farmer broadcasts fertilizer.

fertilizer management systems that will prove effective on upland crops, and identifying the economic and social consequences of this research.

Lowland Working Group

Efficiency of nitrogen applied to lowland rice in Indonesia is very poor. Losses often exceed 60% of nitrogen applied. In spite of these losses, nitrogen use has continued to increase primarily because of the heavy use of government subsidies. However, this policy has posed an increasingly large financial burden on the government. There is a need to identify the most efficient and least cost means of supplying nitrogen to the rice crop.

Field experiments were conducted on flooded rice during the 1982/83 wet season and 1983 dry season at Sukamandi, West Java, Indonesia. Several nitrogen fertilizer strategies were tested. The results suggest that the rate of plant nitrogen uptake is highest between maximum active tillering (about 3 weeks after transplanting) and anthesis (about 6 weeks later). The highest rate obtained was 4.1 kg N/ha/day. Apparent fertilizer nitrogen recoveries were generally high (about 50%-60% for urea split applications and 70%-80% for deep-point placed supergranules. The latter also gave higher grain yields.) There does not appear to be any advantage in splitting urea applications under Sukamandi conditions

where nitrogen fertilizer use historically has been high and water control is good.

In spite of a soil pH of about 4.8, ammonia volatilization losses of 20%-30% are likely to occur from surface broadcast urea, as indicated by floodwater analyses. Losses by this means are probably more important than denitrification losses.

More fertilizer nitrogen is required for a dry season crop than for a wet season crop because of the favorable effect of the fallow period preceding a wet season crop and lower light intensities. Floodwater height has a major effect on the fate of broadcast urea nitrogen. The shallower the water at the early stages, the greater the potential for ammonia volatilization loss.

Economic Analysis of Sulfur-Coated Urea and Urea Supergranules

Two years of on-farm field trials were analyzed to determine the agronomic efficiency and economic viability of alternative nitrogen fertilizer strategies for lowland rice production in Java.

Treatments included different rates of nitrogen, applied as a single broadcast basal application of SCU, deep placement of urea supergranules (USG), single incorporated application of prilled urea (PUI), and conventional broadcast split applications of prilled urea (PU). The agronomic results indicated that SCU and USG were significantly superior to either PUI or PU materials at rates up to 166 kg/ha of nitrogen. The pooled data indicate a slight advantage of USG over SCU. Both SCU and USG had a higher efficiency rating than PUI or PU and required between one-half and two-thirds the quantities of nitrogen to achieve the same yields. Assuming an economic price (elimination of subsidy) for the materials being tested, hand placement of USG gave the highest net return, followed closely by SCU. Both were distinctly superior to either PUI or PU fertilizer.

Upland Working Group

A major objective of the upland working group is to stabilize the cropping systems in the Outer Islands by the appropriate use of fertilizer. The major nutrient deficiency is phosphorus. It is expected that there will be some requirement for nitrogen in later years, but this is not apparent in newly opened land. With use of legumes in the cropping system, the nitrogen input can possibly be kept to a minimum. It also appears that these upland soils show a calcium deficiency rather than an aluminum toxicity as is popularly thought. Work on this aspect of the fertility problem is underway.

Field data from 1983 trials were limited due to extreme drought at most sites; however, eight test sites have been chosen in the Outer Islands for the 1983/84 season. In addition to yield assessment, some emphasis will be placed on dry-matter production and nutrient uptake through the growing season. The crop rotation used will be upland rice, followed by peanuts, followed by cowpea, which may be harvested as a grain crop or incorporated as a green manure depending on the length of the growing season.

Mali

Use of Tilemsi Phosphate Rock

Since 1981, with sponsorship by IDRC, IFDC has been assisting the Malian Government in finding the best possible use of Mali's 20-million ton deposit of indigenous phosphate rock, located in the Tilemsi Valley north of Gao. The objective of the Mali phosphate project is to select the most efficient and economical source to supply the phosphate requirements of Malian agriculture. The first step in this project was the preparation at IFDC Headquarters of PAPR material, made from Tilemsi phosphate rock, at 15% and 30% acidulation levels in both granular and nongranular form. These modified phosphates were then shipped to Mali for a program of field testing being conducted by IFDC in collaboration with the local research institution, the Division de la Recherche Agronomique of the Institut d'Economie Rurale (IER). This collaborative research effort has successfully established intensive research activities both at experiment station sites and in farmers' fields. The agronomic research was complemented by a socioeconomic survey in the most representative farm environments.

On-Station Experiments

Experimental trials were conducted at 10 selected research station sites representing the major soils, climatic patterns, and cropping sequences in Mali (Figure 14). Four experiments were designed as follows:

1. Response to annual application of phosphate rock, PAPR, and superphosphate at four application rates, supplementary to a one-time

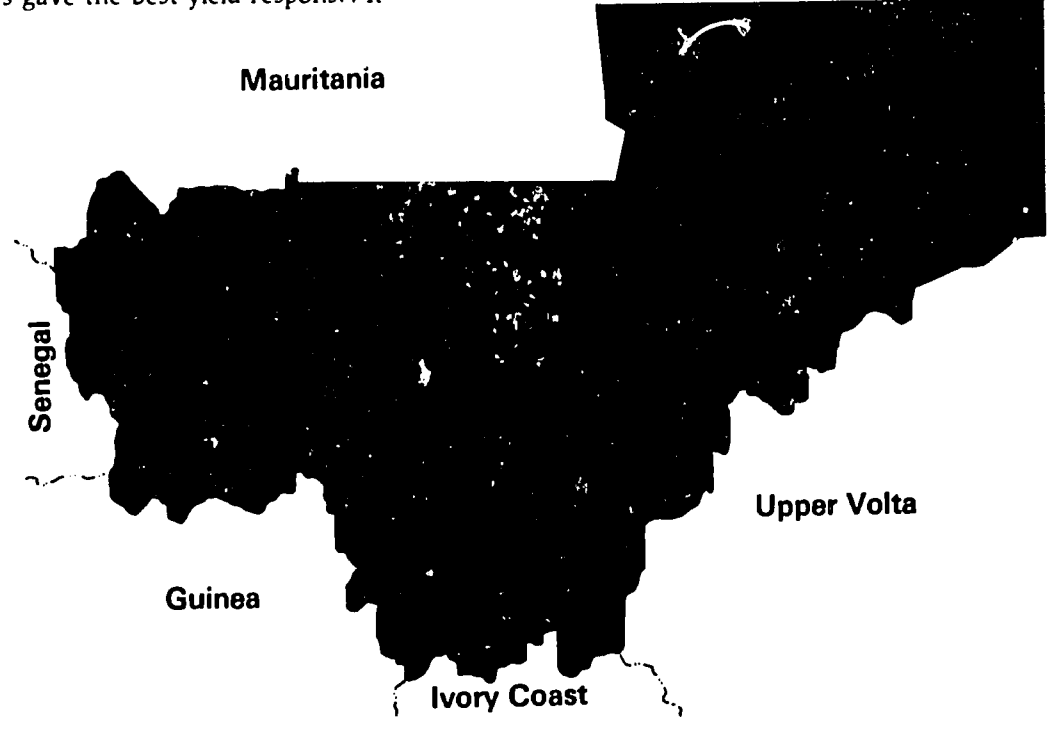
basal application of phosphate rock at three application rates.

2. Response to basal application of phosphate rock, PAPR, and superphosphate at five application rates.
3. Response to annual application of phosphate rock, PAPR, and superphosphate at five application rates.
4. Response to annual application of phosphate rock, PAPR, and superphosphate at four application rates and comparison of three placement methods: broadcast, banded, or hill placement.

Mali suffered a very severe drought in 1983, which dramatically affected crop response to the different phosphates. In areas where rainfall was not a limiting factor, there were no differences in yield responses among the various phosphate tested on the basis of annual applications. Residual effects from the previous year's phosphate rock basal applications were significantly positive; however, in this case, additional annual phosphate applications were not found to be significantly beneficial. As rainfall decreased, the efficiency of less soluble phosphates also decreased, and annual soluble phosphate application complementary to the previous year's basal phosphate rock application significantly increased the yields of cereals.

In the driest areas, annual application of soluble phosphates gave the best yield response. It

At the Koporo-Keniepe Experimental Station, Malian laborers prepare a field prior to planting an IFDC experiment.



Source: Isohyetes map from ICRISAT, 1980, Information Bulletin No. 6.

Figure 14. Location of On-Station Experiments (underlines) and Farm-Level Experiments in the CMDT Zone (□).

should be noted, however, that a basal application of phosphate rock is likely to provide beneficial residual effects over at least 2 years; this result is reassuring to Malian officials who seek to promote the use of Tilemsi phosphate rock over the whole country as one means of reducing expenditures of scarce foreign exchange on fertilizer imports.

Farm-Level Demonstration Trials

In 1983 the Compagnie Malienne pour le Developpement des Textiles (CMDT), as part of their World Bank-financed Mali Sud project, supported a project to coordinate a farm-level evaluation of the use of Tilemsi phosphate rock. The trials were conducted on maize and cotton crops by 60 farmers on representative soils along a north-south axis from San to Sikasso. Average rainfall in this area ranges from approximately 700 to 1,200 mm (Figure 14). The trials were supervised by the IER in close collaboration with the CMDT personnel. A simple nonreplicated 4-plot experiment comparing a zero phosphate check and the recommended practice, using soluble complex fertilizer with two rates of phosphate rock (60 and 120 kg P_2O_5/ha) was conducted in each of the 60 farm trials. At the end of the first year (1983), measurements were taken on crop response for the first season. At the end of the second year (1984), data will be available to measure not only annual but also residual response. The first year's results showed significant response to phosphate rock in all except the driest region. In other words, except in the driest areas, the yield levels obtained with the conventionally used complex fertilizer that contains soluble phosphate were usually not better than those measured on the phosphate rock treatments. In the driest region, the soluble fertilizer sources (complex fertilizer) gave a better yield than the phosphate rock, which confirms results for the on-station experiments.

This program will be expanding in 1984 in other regions of the CMDT zone. In addition, similar farm-level activities might, in the near future, also be developed in other agricultural zones in Mali.

Socioeconomic Survey

Parallel with the Malian project's agronomic research, IFDC, in collaboration with the Division des Etudes Techniques of the IER, initiated a socioeconomic survey of 150 farmers representing the principal agricultural zones in Mali. One-half of these farmers had completed Tilemsi phosphate rock trials of 1 to 3 years in duration under the sponsorship of the Semi-Arid Food Grain Research and Development program.

In addition to identifying factors in the farmer's environment that could affect his decisions with respect to fertilizer use, the survey sought to determine the farmer's own evaluation of

A Malian counterpart agronomist, Mr. Amadou Gakou (left), explains treatments and field application of fertilizer to Malian farmers.

Tilemsi phosphate rock regarding availability, application, crop response, economic return, and potential acceptance as a component of the farmer's crop fertilizer and soil management practices.

The survey showed that the farmers have a strong interest in improving their yields in a cost-effective manner. The role that Tilemsi phosphate rock could play as a cheap and effective phosphate source is of particular interest to farmers. Three major constraints to the acceptance of Tilemsi phosphate rock were identified: (1) the ground rock's powdery or dusty nature, (2) the timing of application, and (3) the larger quantities of material that must be applied as compared with the higher analysis, imported soluble phosphate fertilizer. Nevertheless, farmers generally expressed a desire to continue participating in trials of Tilemsi phosphate rock on their farms. In the CMDT zone, in particular, the demand for Tilemsi phosphate rock increased in those areas where farm-level Tilemsi phosphate rock trials had been conducted.

In view of the strong interest expressed by both the extension agents and the farmers and the intense desire of the government officials to promote use of Tilemsi phosphate rock, future research will focus heavily on direct application of ground phosphate rock in farmers' fields. However, research is also needed to identify those agronomic conditions where Tilemsi phosphate rock, appropriately modified, can be used more economically than either the imported phosphates or ground phosphate rock from other sources.

"Technical assistance is the avenue through which IFDC's mission materializes. Through technical assistance, indigenous production of fertilizers increases, helping to ease hunger in the world. From a personal viewpoint, I get the greatest satisfaction from my job in believing that my calculations will ultimately translate into the smiling face of a well-fed child somewhere."

Mr. Jorge Polo, Deputy Engineering Coordinator
Fertilizer Technology Division, IFDC

Technical Assistance

Technical assistance continued to be an important aspect of the IFDC mission to provide fertilizer know-how to developing countries. This assistance is provided in various ways through activities at Headquarters and overseas. It is the mechanism through which IFDC's research and development accomplishments are transferred to recipients in developing countries. IFDC keeps abreast of all technologies that have potential for helping developing countries improve their food production. These technologies are also transferred to developing countries through technical assistance projects.

Africa

Nigeria Marketing Strategy Development

During 1983 IFDC continued to provide technical assistance in developing a fertilizer marketing system for distributing the production from the Port Harcourt fertilizer complex that is under construction in Nigeria. The estimated onstream date for the 1,000-ton-per-day ammonia, 1,500-ton-per-day urea, and 1,000-ton-per-day DAP and other NPK compound fertilizer facility is mid-1987.

The National Fertilizer Company of Nigeria (NAFCON) has been formed to manage the production and marketing functions of the Port Harcourt fertilizer complex. The marketing system that IFDC recommended in its 1980 Nigeria fertilizer marketing study will serve as the model for the company. That marketing study will be updated to take into account the latest developments in the agricultural sector, especially regarding credit, distribution, warehousing, and quality control measures. NAFCON is scheduled to take over the importation of fertilizers in Nigeria starting June 1, 1984. Fertilizers imported prior to the startup of the factories will be used in a seeding program designed to introduce the farmers to new products that will be produced in the Port Harcourt facilities and to test the marketing system as it is established.

Senegal Marketing Study

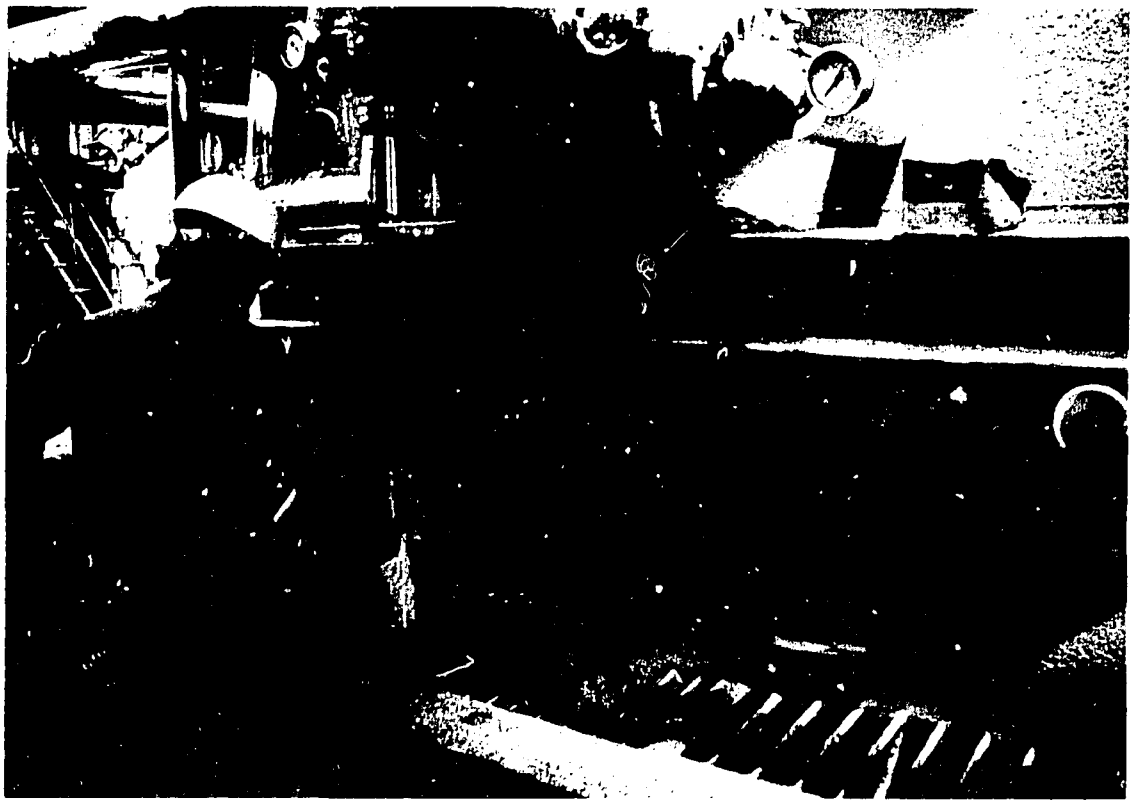
During 1983, at the request of USAID, IFDC provided technical assistance to Senegal in the establishment of commercial arrangements for the supply of essential fertilizers.

IFDC recommended that the Government of Senegal receive from USAID sources 5,000 tons of sulfur and transfer it to the Society for Exploitation of Chemical Industries of Senegal for the in-country production and consumption of NPK grades. In addition, Senegal would receive and transfer 12,000 tons of urea in bulk to the Senegalese Society of Fertilizer and Chemical Products. The latter would package both NPK grades and urea in 50-kg bags and distribute them to the regional development agencies of the Government of Senegal. The Ministry of Rural Development supports the concept of transferring the marketing of fertilizers to the private sector.

The Government of Senegal has since implemented this supply and marketing program.

Niger Agricultural Education Assessment

IFDC participated in an AID-sponsored assessment of Niger's education sector. Under contract with USAID, the Pragma Corporation of Falls Church, Virginia, U.S.A., assembled a team of experts from the various education specialties



Mr. K. G. Ramakrishnan, FPM Production Manager, observes urea-based NPK granulation process.

including an agricultural education specialist from IFDC.

The objective of the study was to analyze the various aspects of Niger's education sector and to prepare a report with recommendations for AID/Niger. The study included all levels of formal education from primary through university, as well as informal, vocational, and management training. The USAID mission of Niger was particularly interested in this study to determine a means for increasing food production through development of Niger's human resources. Agricultural education, both formal and nonformal systems, was the primary concern of the study.

The study revealed that the cost of formal agricultural training far exceeds the cost of nonformal training of farm couples, and the primary constraint facing agricultural education in Niger is its cost and financing.

Fertilizer Situation Study in Zambia

IFDC assisted USAID and Iowa State University in making an assessment of the fertilizer situation in Zambia. Specific objectives of the study were to:

1. Document issues and constraints to Zambia's physical distribution system.
2. Evaluate the existing supply system including local and imported raw materials and finished products.
3. Estimate nutrient and product use in 1986 and 1992.
4. Develop terms of reference for gathering information needed to plan and to implement an efficient fertilizer system.

The study findings indicated that there is an excessive handling of fertilizers through warehousing, transshipping, and physical movement. The study found that the current marketing system requires as many as 30 transfers of fertilizer in transit from the port to the farmer. This excessive amount of handling results in an estimated 24% physical loss of product. The chemical and physical nature of fertilizers used in Zambia contributes to a decline in the quality and a physical loss of fertilizer with each handling.

The study identified a number of existing constraints that result in excessive losses in the fertilizer marketing system and undue cost to Zambia's economy. Several alternatives have been suggested that could alleviate these constraints. Each of these alternatives has technical, economic, educational, and policy implications that require further detailed study and interaction with policymakers before a strategy that is appropriate to Zambia's input supply system

is appropriate to Zambia's input supply system is selected. The following recommendations were proposed:

1. A more detailed study and analysis should be conducted including the development of a detailed plan of action for the design and implementation of an improved fertilizer marketing system to overcome the identified constraints.
2. A plan should be developed to implement proposals for the production and marketing of agricultural-grade limestone.
3. Other supporting activities recommended included:
   a. Donor assistance for storage facilities.
   b. One government agency to be assigned autonomy management responsibility for the marketing system.
   c. A uniform pricing policy to reflect the added value of each marketing component.
   d. Title of fertilizers to be transferred to the importing agency in Zambia to place transportation responsibility on the transporters.
   e. The National Lima Fertilizer Program to give priority to supporting the transfer of technology to farmers on fertilizer use.
   f. A fertilizer marketing training program to be initiated for managers at all levels.

Asia

Malaysian FPM Sendirian Berhad Granulation Project

In the late 1970s the Federal Land Development Authority (FELDA) of Malaysia together with the Agricultural Development Bank of Malaysia and Behn, Meyer & Company (Pte.), Ltd., of Singapore began to investigate the feasibility of producing homogeneous granular compound fertilizers especially designed to fit the needs of the rubber and oil palm estates. A product suitable for aerial application was also desired. Homogeneous, granular, and free-flowing fertilizers were needed to ensure uniform distribution of the nutrients in a single flyover and to facilitate rapid and reliable loading and discharge from the aircraft. The technical aspects of producing the required fertilizer products using the available and most cost-effective raw materials posed problems. To find solutions to the technical production problems, Behn, Meyer & Company (Pte.), Ltd., engaged IFDC in 1979. Following the successful completion of pilot-plant granulation trials at IFDC Headquarters, the company joined FELDA and the Agricultural Development Bank in forming a new company, FPM Sendirian Berhad, to implement the production project.

IFDC engineers provided technical assistance to FPM throughout the design and construction phases of the project. In late 1982 and early 1983 IFDC production engineers provided approximately 7 months of onsite assistance during the preoperational and startup phases of the project. The plant is now operating routinely at about 70% of capacity. Minor process and mechanical modifications and improvements and additional experience in operations are expected to bring the plant to near capacity (140,000-180,000 tons per year depending on grades produced) in 1984.

Agronomic and Economic Market Survey for Thailand

IFDC conducted an agronomic and economic fertilizer market survey of Thailand. This was carried out for the National Fertilizer Corporation (NFC) of Thailand through a subcontract with Foster Wheeler International Corporation. A 4-man team spent 3 weeks in Thailand gathering basic data that were subsequently analyzed and presented to NFC personnel. Major findings were:

1. While Thailand is one of 10 food-exporting countries in the world and the only one in Asia that has been a surplus exporter over the past 30 years, it ranks as one of the lowest countries in Asia in fertilizer use per hectare. The low use per hectare is apparently due to the availability of surplus agricultural land, the small percentage of cropped area that is irrigated and planted to modern fertilizer-responsive varieties, and the low profitability of using fertilizer.
2. Fertilizer consumption (nutrient basis) was 323,900 tons in 1981. Of this total, 162,200 tons was as nitrogen, 126,200 tons as phosphate, and 35,600 tons as potash. Fertilizer consumption is estimated to reach 545,000 tons in 1992 with N, P_2O_5, and K_2O accounting for 265,000 tons, 220,000 tons, and 60,000 tons, respectively.

Over 70 grades of fertilizer are marketed in Thailand, but 20 grades make up most of the tonnage sold. The most popular products sold in 1982 were: 16-20-0, ammonium sulfate, 18-12-6, 11-6-4, 13-13-21, and 15-15-15.

The results of the agronomic and economic market survey served as a basis to establish the size of the ammonia, urea, sulfuric acid, phosphoric acid, DAP, MAP, and NPK production facilities that NFC plans to build on the eastern seaboard.

Latin America

Mexico

Fertilizantes Mexicanos, S.A.

At the request of Fertilizantes Mexicanos, S.A. (FERTIMEX), an IFDC engineer visited the Pajaritos granular triple superphosphate plant near Coatzacoalcos to provide technical assistance concerning the conversion of the existing TSP plant to the production of DAP and multinutrient fertilizer products. This technical assistance was a continuation of the DAP production program initiated during 1982.

The main objectives of the technical assistance visit were to review progress made on the DAP modification; advise plant personnel on the basic operating parameters required for the production of urea- and ammonium nitrate-based multinutrient products; and recommend modifications, additions, and changes required for the production of urea- or ammonium nitrate-based multinutrient products.

The technical assistance provided to FERTIMEX is typical of that required by many other developing countries as they move from the production and use of single-nutrient fertilizers to the more complex and more difficult-to-produce multinutrient products.

Mr. David Rutland, IFDC Chemical Laboratory Analyst, evaluates the physical quality of Venezuela's fertilizer inventory.

Venezuela

Fertilizer Storage Study for PALMAVEN, S.A.

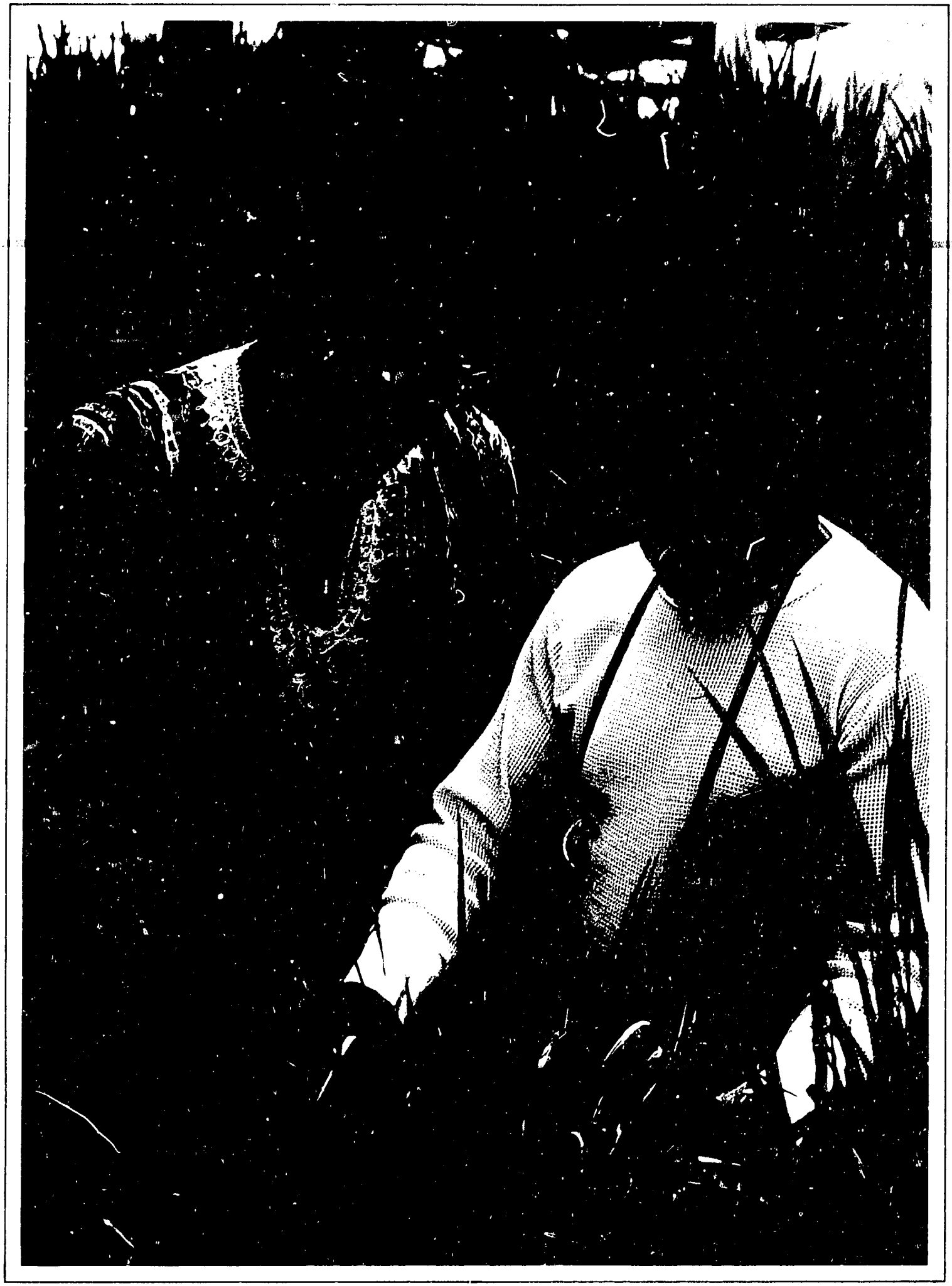
At the request of Petroquimica de Venezuela, S.A. (PEQUIVEN), IFDC sent a team of two staff members to Venezuela to carry out onsite studies to determine the condition of the fertilizer held in storage by PALMAVEN, S.A., in Venezuela. PALMAVEN, a dependency of PEQUIVEN, is Venezuela's fertilizer marketing organization.

The team inspected the fertilizer held in storage by PALMAVEN in 17 sales zones. The fertilizer included 393 lots stored in 75 warehouses totaling over 270,000 tons.

The chemical and physical properties of the fertilizer were determined. In addition to determining the nutrient content, the IFDC team inspected each lot of fertilizer for dampness, bag set, caking, granule integrity, and condition of bags.

A revised commercial value for each lot of fertilizer was determined by decreasing the normal selling price according to a pricing schedule that reflected the chemical and physical deficiencies of each lot.

Recommendations were made to minimize generation of deficient materials in the future.



"Through IFDC's fertilizer efficiency research training programs, participants learn how to conduct fertilizer research aimed at improving fertilizer recommendations to farmers. This very practical training program places emphasis on the establishment of experiments and on the statistical and economic analysis of results."

Dr. Adolfo Martinez, Agricultural Economist
Outreach Division, IFDC

Training Program

The overall goal of IFDC training activities is to develop a cadre of personnel within the developing countries who can acquire, evaluate, and transfer the fertilizer-related technology and skills needed to assist in the production of food.

In 1983 IFDC successfully administered eleven group training programs. These programs included seven that were conducted on a regional basis and four with global outreach. Participating in the 1983 training programs were 292 individuals from 38 different countries. Of these, nine individuals received specialized instruction in programs tailored to meet their specific needs.

Group Training

Marketing

Fertilizer marketing embraces all activities involved in meeting the fertilizer needs of the ultimate consumer—the farmer. The goal of a fertilizer marketing organization is to satisfy the consumer (the farmer) while, at the same time, effectively achieving the organization's objectives. Achieving this goal depends on the organization's ability to implement all of its marketing activities in a timely, efficiently coordinated manner. This requires a team of managers who are skilled in all aspects of marketing fertilizers.

In 1983 IFDC conducted six training programs related to fertilizer marketing. Of these, two were held at IFDC Headquarters and four were held in other regions of the world.

Management

IFDC conducted its seventh annual Fertilizer Marketing Management Training Program during August 15-September 23, 1983, at IFDC Headquarters. Twenty-five people from 16 different countries participated. These countries were: Bangladesh, Colombia, Commonwealth Marianas, Dominican Republic, Egypt, Gambia, India, Indonesia, Israel, Jordan, Nepal, Nigeria, Pakistan, Republic of China, Sierra Leone, and Zambia.

In this program major emphasis was placed on integrated marketing concepts that concentrate on marketing systems development, market planning, and execution. Topics covered during the program included: the world fertilizer situation, the world fertilizer industry, government policy and fertilizer supply economics, marketing factors, marketing decisions, product knowledge, and marketing management concepts. Through the Alpha Fertilizer Marketing Simulation, participants gained "hands-on" experience in decisionmaking and problem solving through simulated real-life marketing situations. Field trips complemented the classroom activities.

Regional Marketing Management

IFDC's fourth Regional Fertilizer Marketing Training Program for the Asian Region was conducted December 4-16, 1983, in Manila, the Philippines, in cosponsorship with the Fertilizer and Pesticide Authority (FPA) of the Philippines. With support from selected specialists from the Philippine Ministry of Agriculture, IRRI, and the fertilizer industry in Asia, a core of IFDC and FPA experts presented the 2-week program. Attending the program were 29 participants from 10 different countries of the Asian region. Training activities included lectures, the Alpha Fertilizer Marketing Simulation, case studies, films, role playing, discussions, and field trips. During field trips to IRRI and to a fertilizer-producing area, participants had an opportunity to observe and study fertilizer factories, warehouses, transportation and handling systems, fertilizer use research in progress, local dealers, and farms.

Data Collection and Analysis

For the first time, a training program on the Data Collection and Analysis for National Fertilizer Sector Studies was conducted March 20-April 3, 1983. Twenty-one people from 13 different countries participated in this program. Participants were from Bangladesh, Burma, Dominican Republic, Egypt, India, Indonesia, Nigeria, Pakistan, Rwanda, Sri Lanka, Sudan, Thailand, and Upper Volta.

The purpose of the program was to increase the participants' knowledge and understanding of those elements involved in preparing a national fertilizer sector study. Specific topics included the types of data required, the use and value of each type of data, data sources and collection techniques, the use of computers, and fertilizer demand and analytical procedures.

The first week of the program was held at IFDC Headquarters; 1 day was spent in Nashville, Tennessee, and 1 week was spent in the Washington, D.C., area visiting organizations that collect and analyze fertilizer-related statistics. IFDC specialists made several presentations and provided overall coordination. Presentations were also given by representatives of various agencies of the Federal Government of the United States including TVA, Statistical Reporting Service and Economic Research Service of the Department of Agriculture (USDA), the Bureau of Mines, and the Bureau of Census. The Food and Agriculture Organization of the United Nations; The World Bank; The Fertilizer Institute; PPI; and the Fertiliser Association of India also participated in this program.

BADC Marketing Management

IFDC conducted a Fertilizer Marketing Management Training Program, May 15-26, 1983, in Dhaka, Bangladesh, for 31 participants employed by BADC. Four IFDC staff members presented the program's general marketing lectures. Bangladeshis from various organizations within the Bangladesh fertilizer sector covered the Bangladesh-specific topics. Nearly half of the BADC participants had not previously participated in any fertilizer training programs; thus, this program provided an excellent opportunity for them to acquire knowledge and skills helpful in their fertilizer marketing work within BADC. This program marked the first time that IFDC has used the Alpha Fertilizer Marketing Simulation as part of a national-level fertilizer marketing training program. The simulation exercise proved very popular with participants. Nearly all participants felt that, by participating in the Alpha Simulation, they had gained ideas or concepts about marketing and management that could be used in marketing fertilizers in Bangladesh. The program also marked the first time that the film "Making the Most of a Miracle," with a Bengali soundtrack, was used in a fertilizer training program in Bangladesh.

Alpha Simulation Training Program for Indonesia

An Alpha Fertilizer Marketing Simulation Training Program was conducted at the P.T. PUSRI Headquarters in Jakarta, Indonesia, June 12-19, 1983, for 21 participants drawn from various P.T. PUSRI divisions, including marketing, accounting, training, and data processing. This program was designed to familiarize P.T. PUSRI personnel with the Alpha Simulation and how the simulation could be used as a tool in training an organization's marketing personnel. An IFDC staff member, working closely with one of P.T. PUSRI's senior marketing specialists, provided instruction during the program. While results of the participants' marketing decisions were being processed by the computer, lecture and discussion sessions were held to give the participants a fuller understanding of the marketing concept and elements that "Alpha" is designed to simulate. In addition to instruction in the classroom, IFDC's instructor worked closely with P.T. PUSRI's data processing personnel to provide training in the actual mechanics of running the Alpha Simulation on P.T. PUSRI's computer.

Production

A number of training programs are offered by IFDC relating to fertilizer production, maintenance, and the management of specific technological processes. These programs are offered at Headquarters or regionally.

Regional NPK Fertilizer Production

The fourth in a series of fertilizer granulation and bulk-blending training programs, the Regional NPK Fertilizer Production Training Program was conducted July 10-16, 1983, in Bangkok, Thailand. Conducted in cosponsorship with the Ministry of Industry, the Ministry of Agriculture, and Cooperatives of the Royal Government of Thailand, the program was targeted for the Asian region. Thirty-three people participated. They represented eight different countries (China, India, Indonesia, Malaysia,

Mr. Lewis B. Williams (left), FMMTP Program Manager, assists program participants, Mr. Hani H. Khoury (Jordan); Ms. Sylvia C.Y. Lee (Taiwan); and Mr. Antonio S. Palacios (Commonwealth Marianas) in solving a marketing problem.

Dr. Dennis H. Parish (left), Director of IFDC's Outreach Division, presents a certificate to Mr. Yong Kil Park of the Republic of Korea, a participant in the Regional Fertilizer Marketing Training Program for the Asian Region.

Pakistan, Singapore, Sri Lanka, and Thailand).

The program focused on the unique production problems of multinutrient granular fertilizer and the increased use of bulk-blended fertilizers. It included an overview of traditional and emerging fertilizer granulation and bulk-blend technologies; factors affecting granulation processes, process design, and operating techniques suited to regional climate and requirements; principles of plant organization and management; and the fundamentals of fertilizer formulation for both chemically granulated and physically blended materials.

Management

IFDC conducted its fourth annual Maintenance and Production Management Training Program, October 3-21, 1983, at Headquarters. There were 18 participants from 11 different countries (Saudi Arabia, Colombia, Peru, Egypt, Venezuela, India, Tanzania, Korea, Indonesia, Malaysia, and Thailand).

Providing an overview of the fertilizer sector, the first week of the program included such topics as fertilizer supply and demand, production economics, and fertilizer production technology and research activities. A 3-day shortcourse on key elements of maintenance management was

also presented. The second week of the program provided participants with the perspective of industry through panel presentations and discussions that were led by representatives of major international- and U.S.-based fertilizer production organizations. The final week of the program was spent in the field observing plant operations and interacting with industry personnel.

Phosphate Geology

At the invitation of the Centre International pour la Formation et les Exchanges Geologiques, Paris, France, an IFDC staff member made a presentation during an intensive course on phosphorite geology held at the University of Dakar, Senegal, November 7-15. The course consisted of lectures, laboratories, and a field trip to an operating phosphate mine. The participants were 10 west African geologists from six Francophone countries and 30 students from the university. The IFDC staff member presented information on the mineralogy, geochemistry, petrography, processing, and marketing of phosphate ores.

Mr. Gene T. Harris (right), Program Manager of the training program on Data Collection and Analysis for National Fertilizer Sector Studies, looks on as Miss Serifunnessa, a program participant, enters data on an IFDC computer terminal for a class exercise.

Use

Fertilizer Efficiency Research in the Tropics

IFDC held a Fertilizer Efficiency Research in the Tropics Training Program, May 2-20, 1983, in cosponsorship with the Universiti Pertanian Malaysia (UPM) at Serdang, Selangor, Malaysia.

Five IFDC staff members presented the program with supplementary presentations given by UPM staff and representatives of other organizations. Twenty-nine people participated in the program. Ten countries were represented: Indonesia, Malaysia, Burma, Sri Lanka, Pakistan, Philippines, Thailand, Bangladesh, India, and Egypt.

The 3-week program emphasized (1) specific procedures for conducting fertilizer trials with new or improved fertilizer materials and application techniques and (2) agronomic, statistical, and economic analysis of results. Half of the training time was devoted to classroom sessions and half to laboratory, greenhouse, and field activities.

Soil Testing, Classification, and Fertility Management

A Soil Testing, Soil Classification, and Fertility Management Training Program was conducted July 11-16, 1983, at IFDC Headquarters. This training program, administered by USDA through Auburn University, entailed several days of presentations by IFDC staff members at Headquarters. Fifteen participants from 13 different countries attended. The countries represented were: Guinea-Bissau, Jamaica, Jordan, Nepal, Saudi Arabia, Sri Lanka, Sudan, Swaziland, Tanzania, Upper Volta, Zaire, Benin, and Belize.

During their stay at IFDC, the group discussed the role that fertilizers play in crop production. Emphasis was given to the relationship between soil testing, soil classification, and fertilizer recommendations. The impact of different soil types and agroclimatic factors on research design and planning was also discussed. Participants learned about the different IFDC agronomy projects throughout the world.

BARC/IFDC Fertilizer Efficiency Research Training Program

At the request of BADC, IFDC presented a fertilizer efficiency training program at Joydebpur, Bangladesh, August 28-September 9, 1983.

Mr. M. Terry Frederick (left), Program Manager for the Regional NPK Fertilizer Production Training Program, presents a graduation certificate to Dr. Suthep Chayabunjonglerd of Thailand.

Thirty-seven Bangladesh researchers from BARC and other Bangladesh agricultural research institutes participated. Two IFDC staff members presented and coordinated the program with supplemental presentations by personnel of BARC, the International Agricultural Development Service, and several Bangladeshi institutions.

Individual Training

IFDC designs individualized courses of instruction for representatives of governments, institutes, and companies involved in fertilizer-sector development and operation. In 1983 IFDC was able to accommodate nine individuals in specialized one-on-one training programs geared to their specific needs. These participants were from eight different countries: Bangladesh, Brazil, Sierra Leone, Jordan, Philippines, Pakistan, People's Republic of China, and Mali. The programs were all different and varied in technical content. The range of individual program curriculums included: bulk blending, bench-scale acidulation of phosphate rock, ore beneficiation, laboratory techniques, computer calculations, and fertilizer dealer development and promotion.

Evaluation

IFDC has incorporated evaluation in all of its training programs. In addition to providing feedback on the conduct of a course, it also serves as a valuable tool in program planning. An evaluation form solicits participant feedback on both technical and administrative aspects of the training program.

To provide an indication of participant objectives and learning, an assessment questionnaire and baseline/followup exercises have been developed. The assessment questionnaire surveys the participants' individual objectives when first arriving for a training program. This includes a survey of the instructional methods that the participants consider to be the most effective and an opportunity for participants to describe an on-the-job problem they would like addressed during the course.

The baseline/followup exercise, designed to measure participant knowledge and learning during the program, is given at the beginning and end of the program. The change in score between the baseline and followup exercises provides one indication of the effectiveness of the training.

With a commitment to improving its training programs and better meeting the personnel development needs of the Third World's fertilizer sector, IFDC recognizes evaluation as a necessary part of its training effort.

Financial Report

1200 FIRST NATIONAL-SOUTHERN NATURAL BUILDING
BIRMINGHAM, ALABAMA 35203
205 328-8700

March 22, 1984

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 and of changes in cash and certificates of deposit present fairly the financial position of International Fertilizer Development Center (IFDC) at December 31, 1983 and 1982, and the results of its operations and changes in its fund balances for the years then ended in conformity with generally accepted accounting principles consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Price Waterhouse

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

CURRENT FUND
(unrestricted)

ASSETS

	December 31, 1983	December 31, 1982
Cash	$ 416,636	$ 301,176
Certificates of deposit	1,271,817	1,653,574
Amounts receivable from donors (Notes 1 and 2)	3,497,299	3,248,020
Other accounts receivable	1,133,205	838,089
Advances to employees	62,425	52,046
Supplies inventory (Note 1)	144,777	136,989
Prepaid expenses	187,652	173,486
	$6,713,811	$6,403,380

LIABILITIES AND FUND BALANCES

	December 31, 1983	December 31, 1982
Accounts payable	$ 315,369	$ 301,728
Accrued annual and sick leave	1,221,946	1,035,152
Deferred revenue (Notes 1 and 2)	3,497,299	3,248,020
Total liabilities and deferred revenue	5,034,614	4,584,900
Fund balance	1,679,197	1,818,480
	$6,713,811	$6,403,380

NONCURRENT FUND
(unrestricted)

	December 31, 1983	December 31, 1982
Amounts receivable from donors (Notes 1 and 2)	$1,775,000	$2,917,298

	December 31, 1983	December 31, 1982
Deferred revenue (Notes 1 and 2)	$1,775,000	$2,917,298

BUILDINGS AND EQUIPMENT FUND
(Note 1)

	December 31, 1983	December 31, 1982
Buildings	$5,734,995	$5,741,090
Equipment	4,235,178	4,225,667
Less - Accumulated depreciation	(3,450,178)	(2,862,607)
	$6,519,995	$7,104,150

	December 31, 1983	December 31, 1982
Accounts payable		$ 6,866
Contract retainage	$ 392	20,924
Total liabilities	392	27,790
Fund balance	6,519,603	7,076,360
	$6,519,995	$7,104,150

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENT OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1983 AND 1982

	Current Fund (unrestricted)		Buildings and Equipment Fund		Total All Funds	
	1983	1982	1983	1982	1983	1982
Revenue:						
Grants (Note 2)	$5,576,119	$6,728,152			$5,576,119	$6,728,152
Recovered project costs	2,781,425	2,367,755			2,781,425	2,367,755
Other	149,865	186,402		$ 6,452	149,865	192,854
Total revenue	8,507,409	9,282,309		6,452	8,507,409	9,288,761
Expenses:						
Research	4,703,394	5,173,751	$ 473,072	464,213	5,176,466	5,637,964
Outreach	2,086,144	2,320,160	41,085	47,206	2,127,229	2,367,366
General and administrative	1,810,093	1,736,963	89,661	86,021	1,899,754	1,822,984
Total expenses	8,599,631	9,230,874	603,818	597,440	9,203,449	9,828,314
Excess (deficiency) of revenue over expenses	(92,222)	51,435	(603,818)	(590,988)	($ 696,040)	($ 539,553)
Other changes in fund balances:						
Equipment acquisitions from unrestricted funds	(47,061)	(129,854)	47,061	129,854		
Fund balances, beginning of period	1,818,480	1,896,899	7,076,360	7,537,494		
Fund balances, end of period	$1,679,197	$1,818,480	$6,519,603	$7,076,360		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENT OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1983 AND 1982

	Research		Outreach		General and Administrative		Total Expenses	
	1983	1982	1983	1982	1983	1982	1983	1982
Personnel compensation (Note 3)	$2,477,378	$2,401,884	$1,063,802	$1,064,395	$1,018,683	$ 964,875	$4,559,863	$4,431,154
Personnel benefits (Note 3)	389,872	400,375	202,178	203,733	167,059	156,617	759,109	760,725
Travel and transportation	306,718	458,623	334,135	471,073	145,749	111,295	786,602	1,040,991
Occupancy	228,146	246,494	111,225	95,923	131,254	105,253	470,625	447,670
Telephone and telegraph	48,381	58,902	28,675	36,250	19,717	22,331	96,773	117,483
Rental of equipment	34,217	71,215	21,232	23,031	15,870	16,802	71,319	111,048
Contractual research and development	492,618	650,180	55,398	36,951			548,016	687,131
Other contractual services	300,847	290,610	134,628	180,322	142,376	126,285	577,851	597,217
Institute of International Education fee (Note 3)					93,102	115,235	93,102	115,235
Materials and supplies	378,741	541,102	111,632	181,299	53,044	91,087	543,417	813,488
Postage	18,003	18,194	9,002	9,097	9,002	9,097	36,007	36,388
Insurance	28,473	36,172	14,237	18,086	14,237	18,086	56,947	72,344
Miscellaneous	4,813		(665)		468		4,616	
Total expenses before depreciation	4,708,207	5,173,751	2,085,479	2,320,160	1,810,561	1,736,963	8,604,247	9,230,874
Depreciation of buildings and equipment	468,259	464,213	41,750	47,206	89,193	86,021	599,202	597,440
Total expenses	$5,176,466	$5,637,964	$2,127,229	$2,367,366	$1,899,754	$1,822,984	$9,203,449	$9,828,314

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 fertilizer know-how 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 only to the extent it is to be used in accordance with the purpose of the organization unless otherwise indicated.

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.

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENT OF CHANGES IN CASH AND CERTIFICATES OF DEPOSIT

	Year ended December 31, 1983	Year ended December 31, 1982
Balances at beginning of year:		
Cash	$ 301,176	$ 239,146
Certificates of deposit	1,653,574	1,660,313
	$1,954,750	$1,899,459
Cash was provided by:-		
(Deficiency) of revenue over expenses	($ 696,040)	($ 539,553)
Charges not requiring (providing) an outlay of cash:		
Depreciation	599,202	597,440
(Gain) loss on disposal of equipment	4,615	(6,452)
Increase in accrued annual and sick leave	186,794	165,172
Cash provided from operations	94,571	216,607
Proceeds from sale of equipment	100	578
Proceeds from issuance of short-term debt	300,000	
Net decrease in advances to employees		40,482
Net decrease in prepaid expenses		128,566
Net increase in accounts payable and contract retainages	6,972	100,709
	401,643	486,942
Cash was used for:		
Purchase of buildings and equipment	40,491	120,028
Reduction of short-term debt	300,000	
Net increase in other accounts receivable	295,116	92,817
Net increase in advances to employees	10,379	
Net increase in supplies inventory	7,788	28,580
Net increae in prepaid expenses	14,166	
Decrease in bank overdraft		190,226
	667,940	431,651
Net increase (decrease) in cash	($ 266,297)	$ 55,291
Balances at end of year:		
Cash	$ 416,636	$ 301,176
Certificates of deposit	1,271,817	1,653,574
	$1,688,453	$1,954,750

NOTE 2 - GRANTS:-

Grants are summarized as follows:

	Year ended December 31, 1983	1982
Grants received -		
United States Agency for International Development (AID)	$ 4,000,000	$ 4,000,000
United Nations Development Programme (UNDP)		3,566,000
International Fund for Agricultural Development (IFAD)	1,000,000	
Australian Development Assistance Bureau (ADAB)	175,300	1,599,888
International Development Research Centre (IDRC)		304,490
Rockefeller Foundation		25,200
Israel Chemicals Ltd.		30,000
Ford Foundation		20,500
Philippines	7,800	10,000
	5,183,100	9,556,078
Unexpended grants reverting to grantee	(500,000)	
Amounts deferred during prior year	6,165,318	3,337,392
	10,848,418	12,893,470
Less - Amounts deferred to future periods	(5,272,299)	(6,165,318)
Revenue recognized in current period	$ 5,576,119	$ 6,728,152

The current grant from AID was amended to provide additional funds of $4,000,000 during each of the years ended December 31, 1983 and 1982, and to extend the grant period from June 30, 1983

to June 30, 1984. The current AID grant provides funds for basic core/operating costs. The use of funds by area is unrestricted except that equipment purchases are not allowed. Funds not legally committed at the grant expiration date will revert to AID.

The IFAD grants, $1,000,000 in 1983 and $880,000 in 1981-1982, provide funds for the first and second years of a three year IFDC fertilizer research program in Africa. Under the provisions of the grants, any grant funds unexpended at the terminaton of the grants revert to the grantee. IFAD grant funds of $280,000 and $220,000 for 1983 and 1982, respectively, reverted to the grantor in 1983 under this provision.

The current year ADAB and Phillipines grants are unrestricted gifts of funds and recognized as revenue in the current year.

Receivables from donors and deferred grant revenue at December 31, 1983 and 1982 are summarized as follows:

	December 31, 1983	1982
AID	$2,355,000	$1,900,000
UNDP	2,485,000	3,200,000
IFAD		220,000
ADAB	320,762	424,078
IDRC	111,537	396,040
Rockefeller Foundation		25,200
	5,272,299	6,165,318
Less: noncurrent portion	(1,775,000)	(2,917,298)
	$3,497,299	$3,248,020

The prior years UNDP, ADAB and IDRC grants provided funds for various research and outreach projects for grant periods of more than one year. The IDRC and ADAB grants expire in 1984 and the UNDP grant expires in 1987. Funds relating to these grants receivable not budgeted for expenditure in 1984 and 1983 are classified as noncurrent at December 31, 1983 and 1982, 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's Board of Directors (from left): Dr. Robert E. Wagner, President, Potash and Phosphate Institute, U.S.A.; Dr. John A. Hannah, (Chairman), President Emeritus, Michigan State University, U.S.A.; Mrs. Marjorie R. Brashier, (Secretary-Treasurer and Ex Officio Member), Administrative Director, IFDC; Mr. Richard Freeman, Director, TVA Board of Directors, U.S.A.; Mr. Adolfo Sisto, General Manager, Industrial Operations, FERTIMEX, Mexico; Mr. Eliseo Restrepo, President, Monomeros Colombo Venezolanos, Colombia; Dr. Ibrahim F.I. Shihata, Legal Counsel, The World Bank, U.S.A.; Dr. Ola Heide, Rector, Agricultural University of Norway, Norway; Mr. Miguel Zosa, President, PHILPHOS, Philippines; Dr. W. David Hopper, The World Bank, U.S.A; Dr. Bukar Shaib, Minister of Agriculture, Lagos, Nigeria; Dr. Anton Amberger, Professor, Institute of Plant Nutrition, University of Munich, Federal Republic of Germany; and Dr. Donald L. McCune (Ex Officio Member), Managing Director, IFDC. (Not pictured: Dr. Entol Soeparman, Director, Research and Development, P.T. PUSRI, Indonesia.)

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