International Health Research Centre

Annual Report 1984

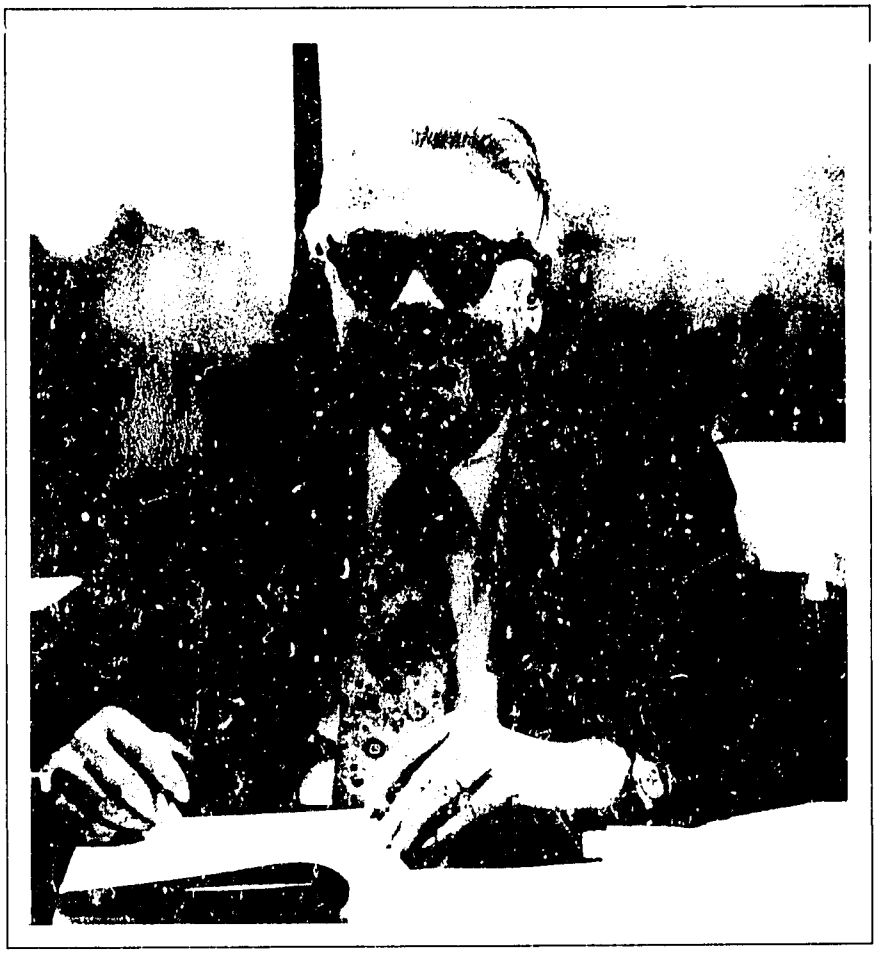
Tenth Anniversary Edition Dedicated to Travis P. Hignett, Special Consultant to the Managing Director

It is with pleasure that we dedicate this tenth anniversary edition of the IFDC Annual Report to Mr. Travis P. Hignett, Special Consultant to the Managing Director.

Since the creation of IFDC Mr. Hignett has devoted many long hours toward the work of the Center. His assistance to IFDC has covered various areas of endeavor. Even before there was an IFDC, Mr. Hignett traveled many miles and devoted his time, talents, and experience to helping developing countries solve their food production problems through the production and use of more efficient fertilizers. His helpful guidance during the formative years was a major factor in the Center's successful beginning.

Besides conducting and directing developments at the Tennessee Valley Authority's National Fertilizer Development Center and later at IFDC that led to many advances by the chemical fertilizer industry, this world-renowned fertilizer authority has devoted much time to putting his ideas and results into writing. With approximately 150 publications to his credit, Mr. Hignett can take pride in being a master craftsman at writing and an effective communicator.

For a down-to-earth approach to a problem or project, younger scientists at IFDC and visitors to the Center from around the world come to Mr. Hignett and benefit from his sage advice.



"For your tireless and selfless devotion to IFDC since its inception, we say 'Thank you, Mr. Hignett.' We are indeed fortunate to have someone of your caliber among us."

The Management and Staff of IFDC

Looking Back at IFDC's Beginnings

by Travis P. Hignett

The beginnings of IFDC were strongly influenced by the experiences of the National Fertilizer Development Center (NFDC), a branch of the Tennessee Valley Authority (TVA). By 1960 NFDC had become well known throughout the world as a center of fertilizer technology and especially for development of new or improved products or processes. However, NFDC was restricted by law or its interpretation to activities that would benefit the farmers and people of the United States except for projects requested (and financed) by other U.S. Government agencies. The U.S. Agency for International Development (USAID), a part of the U.S. State Department, was keenly aware of the need for help to assist the many developing nations to improve their agriculture, and they recognized the important role of fertilizers in agriculture. USAID frequently consulted with TVA about how to meet the growing needs of the developing world.

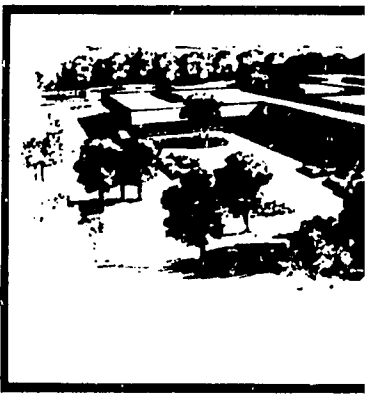
One of the first big jobs was to help South Korea establish a fertilizer industry. At the request of USAID, TVA sent a team of two engineers and one agronomist to South Korea for several weeks in 1963; their report evaluated the needs and recommended the kinds of facilities needed. The project was carried out by industrial firms and became quite successful. South Korea now produces as much fertilizer as it needs and exports some; its agriculture is among the most productive in Asia or the world.

Requests for help by developing countries came with increasing frequency during the 1960s and early 1970s; they involved various aspects of fertilizer: technology, marketing, economics, agronomics, and predictions of supply and demand. Such requests were usually channeled and financed through USAID and coordinated at TVA by Dr. Donald L. McCune, then Director of the NFDC international staff. The work often required a team of two to four people to visit a developing country for 2-8 weeks, and the team members were selected by the heads of the different groups comprising NFDC—research, development, operations, design, agricultural development, etc. We, at TVA, who were required to make these selections found it increasingly difficult to find the best qualified people for each job because each of our staff was assigned to NFDC (national) projects and the TVA Board of Directors of that time insisted that TVA's program should have priority over overseas work.

The requests for help swelled with the alarming food and fertilizer shortages and skyrocketing prices that began in 1973 and were generally thought to be caused by the oil crisis although the neglect of agriculture by some developing-country governments may have contributed to the food crisis. The problem became a matter of international concern. In April 1974 Henry Kissinger, the U.S. Secretary of State, addressed the General Assembly of the United Nations and proposed an international effort supported by the United States to improve fertilizer for developing countries. This idea met with ready acceptance, and several alternative proposals were put forth. In view of TVA's success in fertilizer development, both national and international, and in further view of the excellent facilities available at TVA, it was decided to locate the center in Muscle Shoals, Alabama, on land offered by TVA adjacent to the NFDC. However, it was decided to make the center truly international and not an agency of the U. S. Government although funds for establishing the facilities were provided by the United States as promised. This arrangement was much less costly than setting up a new center elsewhere and enabled activities to begin much sooner. In fact while the plans were still being discussed, TVA continued its international activities supported by USAID. During 1974 I (having retired from TVA) participated in fertilizer industry planning missions in the Philippines, Indonesia, and Pakistan.

In October 1974 IFDC was established as a private, nonprofit corporation under Alabama law (later designated as a nonprofit public international organization), and Dr. McCune became the Managing Director.

Operating in temporary offices in a bank building and a small TVA laboratory building (formerly a TVA Medical Center), IFDC began recruiting a staff in 1975. We were able to start some laboratory work in the temporary facilities. For example, bench-scale phosphate rock beneficiation facilities were set up in a former medical laboratory and even a small granulation pilot plant



"A Decade of Progress, 1975-85"

was located in a garage that formerly housed an ambulance.

IFDC was started with only a few people, mostly drawn from TVA by mutual agreement among IFDC, TVA, and the individuals concerned. Naturally, TVA did not wish to lose many of its staff, and IFDC wanted to build an international staff as rapidly as qualified people from other countries could be hired.

Meanwhile, we were planning our new buildings—a main building with research laboratories, offices, a training center, a small greenhouse, and a small library (we were allowed access to TVA's excellent library and contributed to its support). Another building housed pilot plants and associated offices. Our building program was based on a planned staff of some 65-70 employees of which 35-40 would be technical people. Now that we have some 180 employees we may be a bit cramped, but quite a few are stationed at other centers overseas.

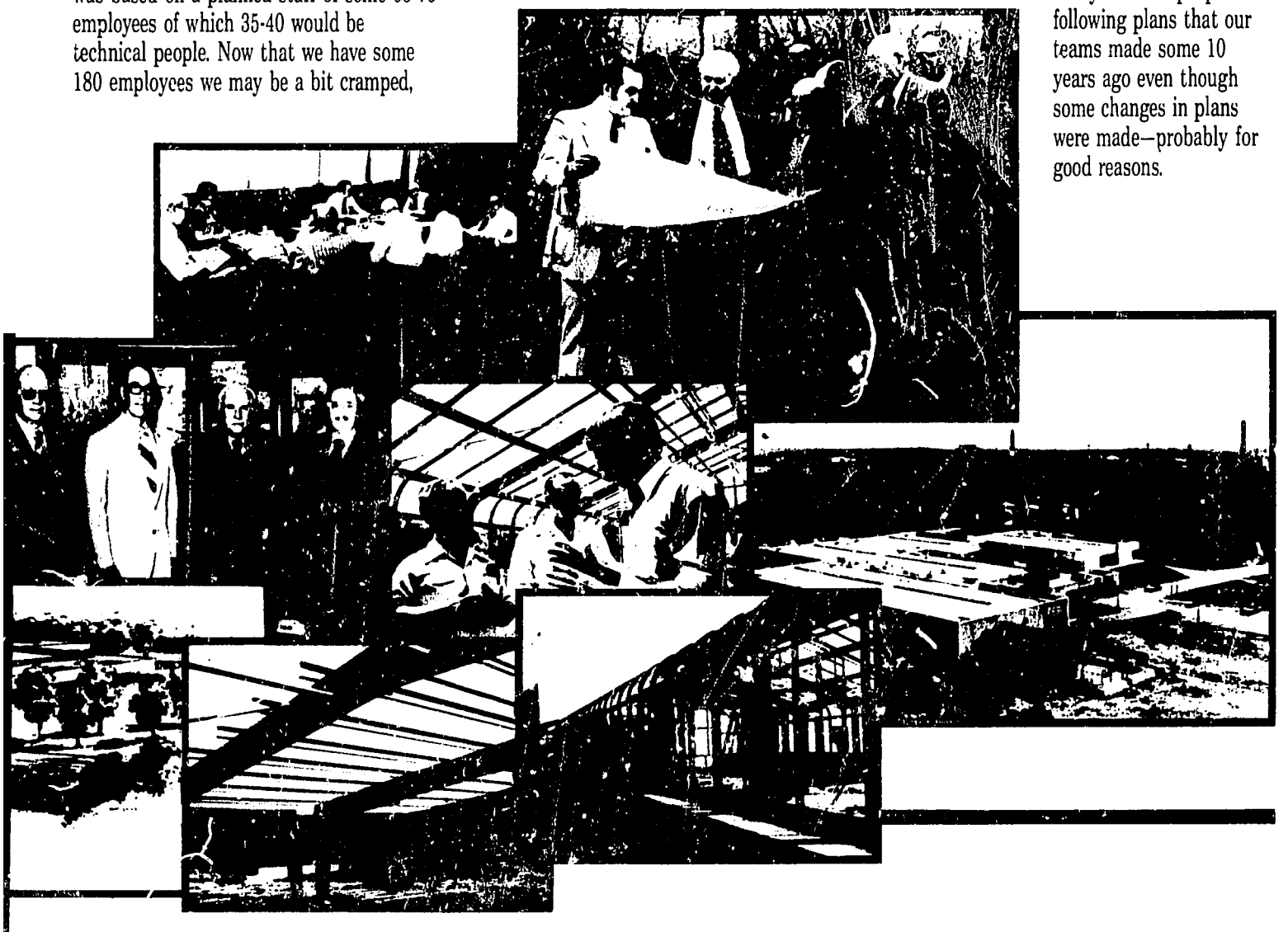
IFDC is the first international agricultural research center that was established to work on an input to agriculture. All other international centers work on outputs to agriculture either on specific crops or on animal problems.

IFDC was set up in recognition that the temperate-zone agriculture could no longer be counted upon to feed a world population that continues to grow by 80-90 million people per year. It was recognized that if the world was to be fed most of the food must be produced in the countries where it is consumed.

Historically, the tropics and subtropics—the target area of IFDC—are having increasing difficulty in producing enough food to feed their people. This largely results from the fact that tropical soils are natively quite infertile. However, evidence is now accumulating that a more productive agriculture can exist in the tropics if soil fertility is supplemented and replaced on a continuing basis. The potential for a long-growing season or year-round agriculture wherever rainfall is adequate or irrigation potential exists greatly adds to the food production potential of the tropics.

It is with great satisfaction that I look back on the overseas missions and meetings in developing countries and recall the eagerness of the people to learn. It was a pleasure to be able to give them useful information or tell them where to find it.

Many of these people are following plans that our teams made some 10 years ago even though some changes in plans were made—probably for good reasons.



Report From the Management

During the year 1984, in agricultural development circles it was brought home to us again that if the developing world is to feed itself, long-term strategies must be developed and implemented to help these countries become more self-sufficient in food production. As is well recognized, one of the keys to this self-sufficiency is increased and efficient use of appropriate fertilizers.

The International Fertilizer Development Center stands ready to meet this challenge and during 1984 furthered its mission of "developing more efficient fertilizers and fertilizer practices to increase food production in the developing countries especially in the tropics and subtropics."

The Center's research program made new strides in the development and application of fertilizer technology. For example, through the Center's continued research to develop means of controlling losses of fertilizer nitrogen, new inhibitors were synthesized. It is hoped that these new inhibitors (chemicals to prevent or slow down losses of fertilizer nitrogen) will provide developing-country farmers with a cost-effective means of reducing their losses of fertilizer nitrogen and, thus, help to place more food on their tables.

Another very practical part of IFDC's work is in the field of phosphate research. This component of the research program is helping developing countries find ways to use one of their natural resources—phosphate rock—to produce fertilizer that can, in turn, help feed their people. The past year at IFDC saw the advancement of several cost-effective approaches to phosphate fertilizer production.

During 1984 IFDC's national program component continued to progress and expand. This component seeks to ensure that the fertilizer technology developed by IFDC is indeed appropriate to the needs of the countries for which it is intended. Through cooperative work with various national agencies of developing countries, including at present Bangladesh, Colombia, Indonesia, and Mali, IFDC in partnership with national researchers actually conducts "on-the-scene" evaluation of the technology produced by its research and development programs.

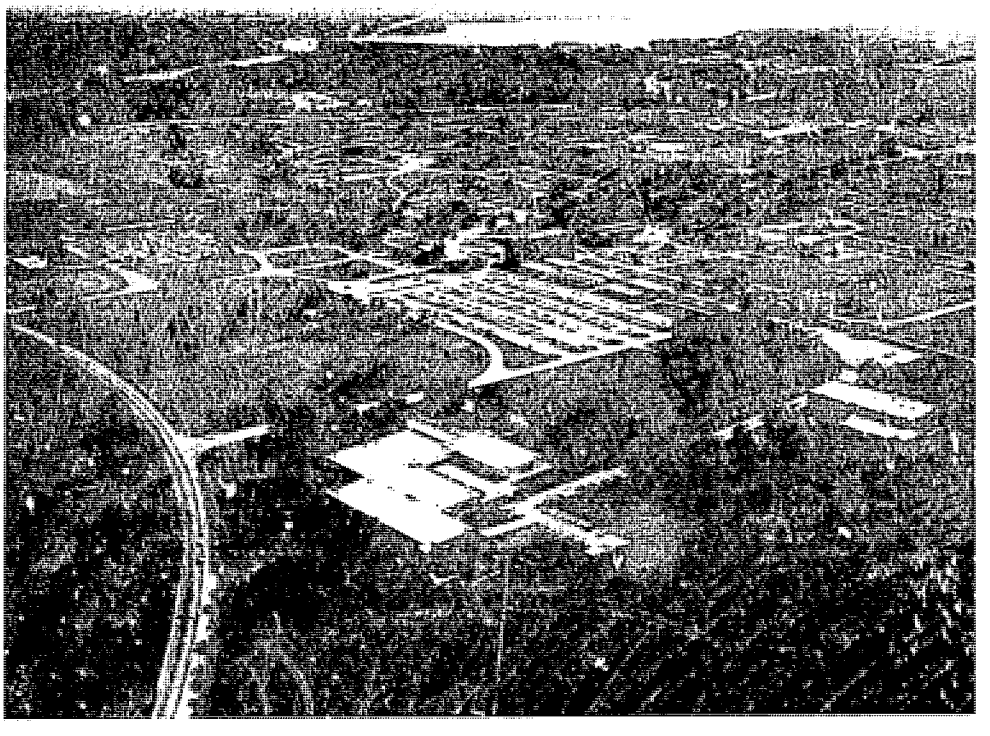
Our activity in the technical assistance area during 1984 was centered primarily in Africa with other projects conducted in Asia and Latin America, as well. Because it seeks to solve problems facing the developing-country fertilizer sector, this phase of our activities represents a very practical, down-to-earth application of IFDC's developments in fertilizer technology.

Our training programs continue to play a vital role in helping to transfer technology produced by IFDC and other research and development groups. By enhancing the knowledge and capabilities of fertilizer-sector personnel of developing countries, IFDC's training programs are helping to ensure that the Center's accomplishments in fertilizer research and development will be effectively and efficiently implemented in the developing world. During 1984 through its eleven group training programs, the Center added 258 more people from 45 developing countries to the ranks of IFDC training alumni.

As IFDC enters its 10th year, it does so with a feeling of satisfaction. The food situation in most countries of Asia and Latin America has vastly improved over that of a decade ago. The increased availability and use of fertilizer have been major contributing factors. IFDC is fortunate to have played a role in this change. However, as encouraging as these improvements may be, the worsening food situation in Africa illustrates the severity of the struggles still facing many countries. Even with the favorable situations that now prevail, Latin America and Asia are still very much in a delicate balance where poor policy choices or shifts in weather could again plunge those areas into food shortages. IFDC will intensify its efforts to help ensure that fertilizers are used more extensively and efficiently.

Donald L. McCune
Managing Director

Paul J. Stangel
Deputy Managing Director



Aerial view of IFDC (foreground) and NFDC/TVA (background).

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Photo on opposite page:
Since its inception, the main goal of IFDC's nitrogen research progr has been the reduction of losses of fertilizer nitrogen. Shown here, I Chemist Angie James prepares soil extract for distillation.

Research Program

Even though fertilizer consumption in the developing countries increased by nearly 140% during the past 10 years (from 22% to 35% of total world consumption), more rapid advances in the agricultural sector must be made if the everburgeoning population of the developing world is to be fed. World population during 1983 reached 4.7 billion, with 74% of this total living in the developing countries. According to some projections by the year 2000 world population will reach 6.3 billion, with 78% of this total residing in the developing world. To help feed this ever-increasing world population, tropical and subtropical soils must supply a large share of food. Food supplies will need to be increased by 50% by the year 2000 and by 100% some 15 or 20 years later.

To increase food production, arable land must be cropped more intensively. Of the agricultural technologies used to increase food production rapidly, the most effective one is increased use and efficiency of fertilizers. To achieve this end, IFDC was founded to serve the fertilizer needs of the developing countries, especially those of the tropics and subtropics.

IFDC's overall research program during 1984 was primarily focused on nitrogen, phosphorus, and sulfur. Additional research was conducted on multinutrient fertilizers and the socioeconomics of fertilizer use.

During 1984 our scientists furthered their research on improved efficiency of fertilizer nitrogen. Various forms of modified urea were prepared for agronomic testing. In addition, IFDC continued its research on inhibitors (chemicals to control losses of fertilizer nitrogen) and improved fertilization practices.

IFDC's phosphate research program continued its mission to assist developing countries in making better use of their indigenous fertilizer resources. Several cost-saving ideas, such as partially acidulated phosphate rock, were advanced still further. A number of experimental products were produced for agronomic testing on experiment stations and farmers' fields. Several special research and development projects were carried out on a reimbursable basis for fertilizer companies or developing-country governments.

To meet the need for multinutrient fertilizers in developing countries, IFDC devoted considerable effort to the production of various nutrient combinations of nitrogen, phosphorus, and potassium during 1984.

To help alleviate the increasing sulfur deficiency in tropical agriculture, IFDC soil scientists conducted various studies to evaluate the potential use of elemental sulfur mixed with nitrogen and/or phosphate fertilizers as a sulfur source for crop production.

During 1984 work was completed on a state-of-the-art appraisal of micronutrient research in tropical agriculture. The resulting publication, scheduled to be released in 1985, evolved out of a study tour of 20 tropical countries conducted during 1982/83 to assess their micronutrient problems.

Socioeconomic research continued to gather information needed for the establishment of research and development policies. IFDC's economics and sociological research has developed into four major work areas: a fertilizer evaluation progr[illegible] information system, computer simulation modeling, fertilizer adoption, and market situation and outlook.

If mankind is to meet the challenge of feeding the predicted population of the year 2000, agricultural research must be intensified. It is crucial that increased attention be focused on the development and transfer of new agricultural technologies, including new and improved fertilizer. Since IFDC is at the "cutting edge" of research and development of new and improved fertilizers, the Center stands ready to meet the challenge.

During 1984 IFDC scientists continued their efforts to understand better the mechanisms and magnitude of nitrogen losses and to develop cost-effective methods for improving the efficiency with which nitrogen is used. Early in IFDC's program development it was recognized that the fertilizer nutrient nitrogen was not being used efficiently, especially in Asia where urea is the predominant fertilizer.

To illustrate the potential impact of improved nitrogen use efficiency, urea can be used as an example. In 1983/84 the estimated consumption of nitrogen in the form of urea in the developing countries was 14 million tons. An average use efficiency of 40% translates into losses of US $3,300 million for 1983/84. Because the prices of nitrogen fertilizer are expected to rise sharply in the future, the loss will loom even greater.

Several contrasting approaches to solving the problem are currently being investigated at IFDC. As an alternative to the conventional prilled urea to which the developing-country farmer is accustomed, IFDC is preparing various forms of urea, such as urea supergranules (USG) and chemically modified types for agronomic testing. In addition, IFDC is comparing potentially improved fertilization practices, such as deep placement, to increase the efficiency of nitrogen fertilizer. Deep placement involves: (1) size modification of the urea to facilitate deep placement by hand and (2) a change in farmer management. Various groups are developing experimental machines for deep placing supergranules, conventional granules, and prills. A farmer must transplant rice in straight, even rows if he uses a machine to deep place fertilizer. If he chooses to deep place fertilizer by hand rather than by machine, the farmer faces a relatively high labor requirement. Nevertheless, improved agronomic efficiency has been achieved in more than 1,000 sites through the use of deep placement. IFDC is attempting to evaluate the total deep-placement concept at selected sites in developing countries.

The Center is conducting equally important research to modify nitrogen fertilizer materials so that farmers will not be forced to change their fertilization practices. Some examples of this research are: combination of urea with a urease and/or nitrification inhibitor, various chemically modified forms of urea, and controlled-release forms of urea. In most cases these new products are undergoing screening tests in the laboratory and greenhouse. Promising products will be field tested during 1985. Emphasis will be placed on the economics of production and use when sufficient data have been obtained.

Using molecular models, Dr. Ramiro Medina, Enzyme Biochemist, studies the interaction of inhibitors and the active site of urease.

Product/Process Development and Modification

Urease Inhibitors

Potential New Types—A project to identify potential new forms of urease inhibitors, which was partially sponsored by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), was begun in late 1983. The objective is to combine small quantities of a chemical with urea to control urease activity and thereby control the urea hydrolysis rate. Urease is an enzyme that is present in soils. When exposed to the soil containing urease, urea undergoes rapid hydrolysis (decomposition) to ammonia and carbon dioxide. If the ammonia is not absorbed by the soil or plant roots, substantial losses can occur. Control of the rate of ammonia formed by urea hydrolysis in rice paddies should lead to improved nitrogen use efficiency. The new class of inhibitors presently being developed by IFDC should have more stability and lower cost than the urease inhibitor phenylphosphorodiamidate (PPD), which is being used now.

The project focuses on three activities: (1) chemical synthesis of inhibitors, (2) determination of urease inhibition at a constant pH (pH-stat method), and (3) initial screening of inhibitors through soil incubation studies.

Promising results have been obtained with some new phosphonitrilic-based materials (cyclotriphosphazatriene derivatives). Substitutions in these compounds should alter the stability, effectiveness, and cost. TVA and IFDC are characterizing these compounds. Equipment is being assembled so that sufficient quantities can be produced for field evaluation at the International Rice Research Institute (IRRI) in 1985.

Synthesis of Phenylphosphorodiamidate—IFDC investigated two synthesis procedures in batch laboratory-scale equipment for preparation of PPD. Synthesis is based on ammoniation of phenylphosphorodichlorodate (PPDCL), whereby PPD and byproduct ammonium chloride are formed. Best results (up to 99% theoretical yield) were obtained by suspending PPDCL in chloroform during ammoniation. This technique provides a lower cost and technically viable alternative for producing small quantities of PPD to be used in the nitrogen research program. However, the cost of PPD is still relatively high; therefore, lower cost, more effective substitutes are being sought.

Urea Supergranules

Urea particles weighing 1-2 grams each intended for deep placement in rice paddies are called "supergranules." Agronomic results in Asia continued to confirm that under most soil-cropping-climatic conditions, supergranules give a higher rice yield than that obtained from multiple surface applications of prilled urea. Most tests have been conducted with hand placement, but experimental machines are being developed by IRRI; Fujian Academy of Agricultural Sciences, the People's Republic of China; and the Netherlands Fertilizer Institute.

In a recent study, IFDC technologists compared the technical routes for production of USG. They evaluated processes such as melt granulation (rotary drum, pan, and fluid bed) and briquetting and concluded that urea supergranules produced in a relatively small plant (250-500 tpd) will be more expensive than urea prills—normally made in large plants (1,700 tpd). In large plants urea supergranule production by melt granulation is more favorable but still more expensive than the production of urea prills. Where solid urea (dust, prills, or crystals) is available, briquetting is cheaper than melt granulation. A workshop held in Indonesia indicated a number of areas that need more research and evaluation on the technology of production and use of supergranules. Further, only limited pilot-plant trials (1-2 tph) for supergranule production by the alternate routes have been conducted thus far.

Synthesis of ^{15}N Urea

IFDC chemists continued their studies of the synthesis of ^{15}N-labeled urea by reaction of ^{15}N-ammonia with molten phenylcarbonate. The labeled urea is used in numerous agronomic studies in Headquarters' greenhouses and fields in developing countries. Our chemists have purified the material by removing the byproduct phenol and recrystallizing the crude urea. They obtained a 90% yield of labeled urea; the final urea product is 99% urea.

Urea-Formaldehyde Reactions

IFDC continued its study of the mechanisms of urea-formaldehyde reactions. The work is important for two reasons: (1) formaldehyde is used to condition urea in many developed and some developing countries to improve storage and handling properties and (2) urea-formaldehyde reaction products are potential controlled-release nitrogen fertilizers.

During 1984 our chemists used a high-performance liquid chromatography technique originally developed by IFDC to study urea-formaldehyde reactions. This technique enabled the chemists to isolate and characterize a

D. W. Rutland, Physical Properties Specialist (left), and J. J. Schultz, Engineering Coordinator, examine the physical quality of experimental urea supergranules produced by the briquetting process.

new compound, biuretmethyleneurea (BMU). Depending on reaction conditions of urea with formaldehyde, various amounts of the following compounds are normally found: urea, biuret, triuret, methylenediurea, BMU, and dimethylenetriurea. Small samples of urea-paraformaldehyde reaction products were also produced for greenhouse testing.

Preparation of Experimental Nitrogen Fertilizers

A number of experimental nitrogen materials were made by the Fertilizer Technology Division for agronomic evaluation. An evaluation of these materials is discussed in the section, "Agronomic Research." Materials included:

1. Mixtures of urea and various other fertilizer materials.
2. Urea and paraformaldehyde reaction products of varying concentrations.
3. Urea and experimental urease inhibitors.
4. Various coated products.

Some of these fertilizers were labeled with ^{15}N.

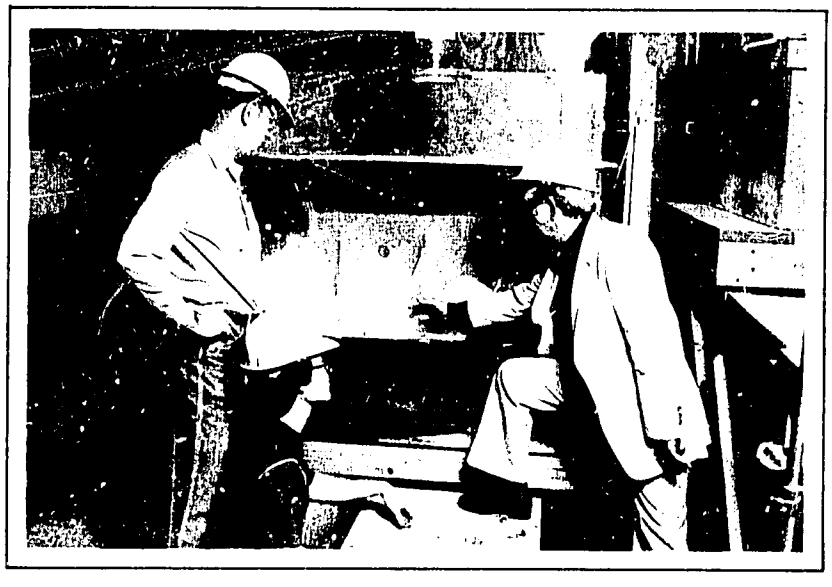
Agronomic Research

Rice in South and Southeast Asia

The main objective of the Lowland Nitrogen Program is to improve the efficiency of nitrogen fertilizer used on rice. Rice is the staple food for almost two-thirds of the world's population and accounts for almost 50% of the total cereal production in developing countries. Newly developed high-yielding varieties of rice have become widely adopted in Asia and have greatly improved production. However, the new varieties yield only slightly more than traditional varieties unless more production inputs, particularly nitrogen fertilizers, are used as well. Unlike most of the traditional varieties, the new varieties are extremely responsive to nitrogen fertilization, and frequently yield is doubled by the optimum application of nitrogen.

Urea is the principal nitrogen fertilizer available in developing countries. Losses of nitrogen applied as urea to flooded soil can be extremely high. Past research conducted by IFDC scientists has shown that nearly one-half of the nitrogen can be lost through ammonia volatilization in a few days following fertilization. During 1984, as part of the IFDC/IRRI collaborative project, IFDC scientists conducted additional field experiments in the Philippines using the micrometeorological technique for directly measuring ammonia volatilization. A recently developed technique to directly measure denitrification losses was used in the same field study in the Philippines. The technique involves applying urea that is 95% labeled with the stable isotope of nitrogen (^{15}N). Nitrogen that is evolved as nitrogen from denitrification is then measured by placing a cover over the flooded soil for various periods and accumulating denitrified nitrogen in the air atmosphere under the cover. The total nitrogen under the cover is then "fixed" with oxygen (converted to nitric oxide) by use of an electric arc. After conversion to the fixed forms in the laboratory, the amount of denitrified fertilizer can be estimated by using a mass spectrometer to measure the amount of labeled nitrogen in the sample.

In this experiment, 53% of the fertilizer nitrogen was lost through ammonia volatilization, and only about 1% was additionally lost as denitrified nitrogen, according to the ^{15}N balance. This 1% was accurately accounted for by use of the newly developed technique, which directly measures denitrification. The method demonstrated great sensitivity in measuring less than 1% of the fertilizer nitrogen, and showing a definite diurnal loss pattern. Losses began soon after fertilization and peaked at 6 days later; after this time they decreased. This promising technique will be used in future studies under conditions in which denitrification losses are expected to be greater.



J. R. Clemmons, Chemist (left); B. W. Biggers, Chemist; and O. W. Livingston, Director of the Fertilizer Technology Division, observe the flow pattern of urea in an experimental small-scale spouted-type fluidized bed.

Dr. R. J. Buresh, IFDC Soil Scientist stationed at IRRI, and Philippine field assistants conduct measurements in a rice experiment designed to determine the efficiency of nitrogen fertilizer.

Fertilizer Management for Rice

Past research by IFDC scientists has shown that the amount of ammonia volatilization that will occur from flooded soils fertilized with urea depends on the amount of urea dissolved in the floodwater. In turn, the efficiency of urea incorporation by basal applications depends on soil conditions and the amount of water on the soil when the fertilizer is incorporated. This was demonstrated in a greenhouse study in which a puddled soil was repuddled either 1 week or 2 hours before the fertilizer was broadcast and incorporated. Floodwater depths were controlled at 0, 0.5, and 1.0 cm at incorporation and for 2 days after the urea application. Water was then added to a 2-cm depth in all of the treatments. The amount of urea lost from each of these treatments (Figure 1) was increased by having more floodwater on the soil surface and by puddling the soil shortly before the fertilizer was added. More urea remained in the floodwater as the water depth increased, and apparently absorption of the nitrogen by the soil was

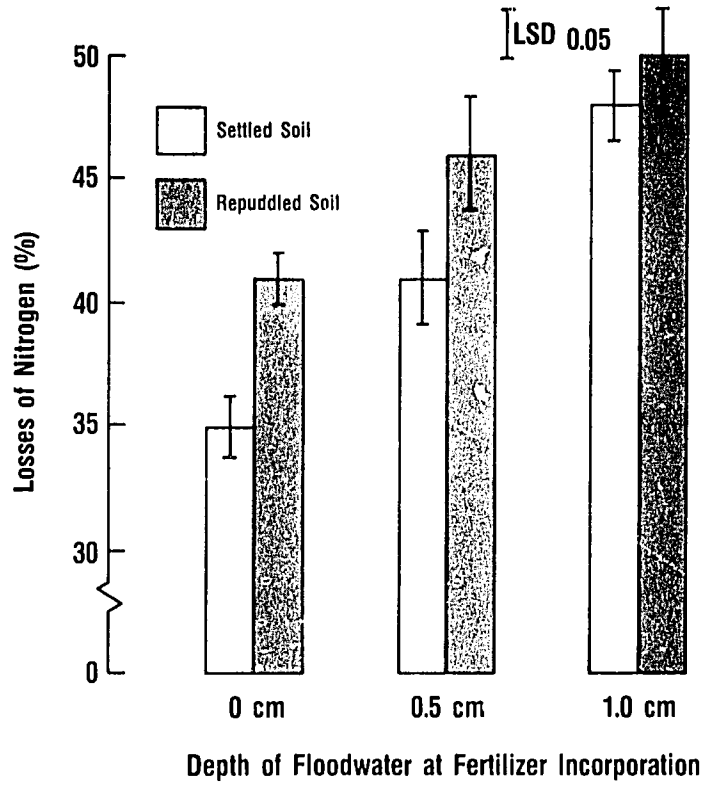


Figure 1. Ammonia Volatilization Losses as Affected by Water Depth and Condition of Soil at Incorporation, Greenhouse Experiment.

decreased when the soil was repuddled shortly before the urea application.

Product Evaluation for Rice

A Urease Inhibitor—IFDC scientists have shown that PPD is the most potent urease inhibitor found to date. PPD inhibits the action of the urease enzyme that converts urea to ammonia. By slowing the action of this enzyme, more of the urea is maintained as urea and not converted to ammonia, which can be lost through ammonia volatilization.

It has been difficult to establish a clear yield advantage of an experimental urea treated with PPD over an untreated commercial urea product. A 10% yield improvement is rarely statistically significant, but it may be economically important to a farmer. IFDC scientists have continued their preliminary evaluation of PPD. In the past, PPD has consistently increased nitrogen uptake by the plant and decreased ammonia volatilization losses from urea applied to field rice. However, rice yields were not significantly increased under greenhouse or experiment station conditions.

Recent research has shown that delayed applications of urea with PPD to rice have a positive effect on grain yield. A delayed split application of urea with PPD resulted in a yield response of about one-half ton (Figure 2). The delayed split application of urea without PPD performed the same as the recommended practice of two-thirds basal incorporation and one-third applied at 5-7 days before the panicle formation begins. Point placement of urea supergranules, the best fertilization practice found to date, gave yields that were similar to those of the delayed split application of urea with PPD. IFDC has initiated further research to study the effect of this inhibitor in delayed application, a common farmer's practice.

Great progress was made in 1984 in developing new urease inhibitors that have a longer or delayed inhibitory effect. These materials have been tested in laboratory experiments but have not as yet been studied in greenhouse and field experiments. The materials show greatest promise when applied in combination with PPD to obtain initial as well as long-term urease inhibition.

Urea-Formaldehyde Fertilizers—In 1984 several urea-formaldehyde fertilizers produced by IFDC were agronomically evaluated. Several products containing paraformaldehyde were prepared and evaluated on wetland rice. Ammonia volatilization losses were measured directly to determine the potential of these materials in reducing nitrogen losses from flooded rice systems (Figure 3). An addition of 12% paraformaldehyde to urea reduced ammonia volatilization losses by 19% of the applied fertilizer nitrogen. Although no increase in grain yield was measured, a 10% increase in nitrogen uptake of applied nitrogen was observed with the addition of 12% paraformaldehyde to urea. These materials warrant further testing to assess their potential for improving nitrogen fertilizer efficiency in wetland rice.

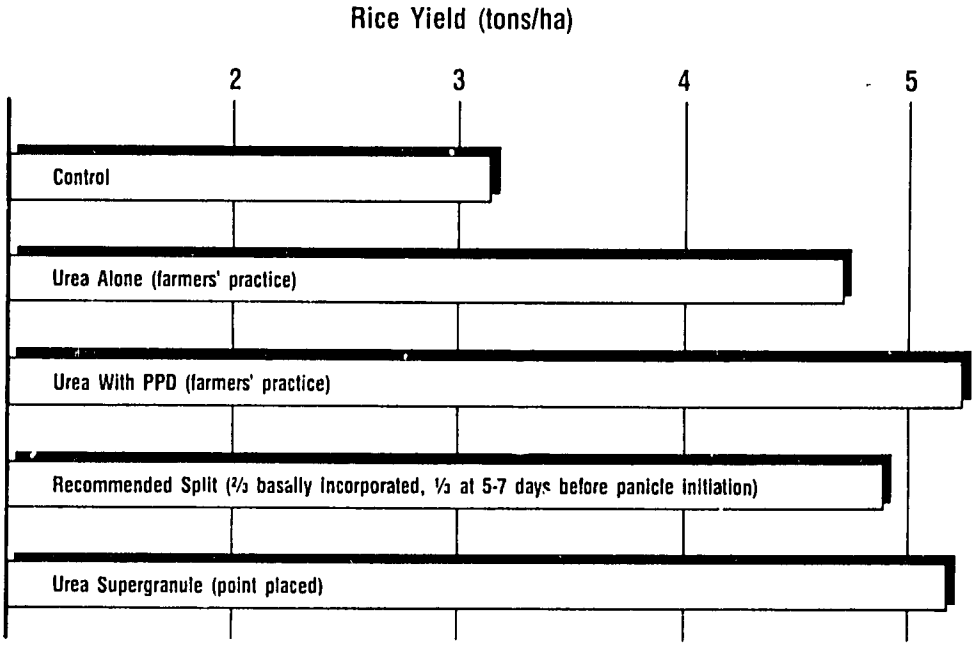


Figure 2. Effect of PPD on Delayed Application of Urea (Farmers' Practice) Versus Supergranule Application.

Fertilizers for Irrigated Wheat in the Punjab

In 1982 under a contract with the Indian Council of Agricultural Research (ICAR), IFDC began research on irrigated wheat in the Punjab, the wheat basket of India. This research was conducted in cooperation with the Punjab Agricultural University (PAU) in Ludhiana, India.

In the Punjab wheat is grown on about 2.8 million ha, largely in rotation with irrigated rice. Most of the soils in the wheat-growing area are light textured. Rainfall during the post-rainy season (October-May) is about 125 mm. Wheat can be grown in the post-rainy season only if irrigation water is available from tubewells or canals. Irrigation water is usually applied in six irrigations of 3 inches each (total of about 460 mm). The locally recommended method for nitrogen fertilization is split application after irrigation

in order to avoid anticipated losses due to leaching. The average rate of nitrogen application for irrigated wheat in the Punjab is about 114 kg N/ha, and the average wheat yield is about 2.7 tons grain/ha.

Collaborative experiments between IFDC and ICAR/PAU were conducted from 1982 to 1984 on irrigated wheat grown in the Punjab. One of the main objectives of these experiments was to determine the effect of timing of irrigation relative to fertilizer application. Another objective was to determine the effects of source of fertilizer nitrogen on its use efficiency and losses. Fertilizers used in the experiments included urea, urea-dicyandiamide (DCD), urea-PPD, and potassium nitrate. Urea is the major nitrogen fertilizer used in the Punjab. Potassium nitrate was included to determine whether leaching of nitrates (or denitrification) would be an important nitrogen loss mechanism in these soils. If so, recoveries of nitrogen from potassium nitrate would be expected to be lowest and from urea-DCD (a nitrification inhibitor) to be highest among the fertilizers tested in the experiment. All fertilizers were split applied; the basal application was broadcast and incorporated after an initial irrigation; and the topdressing was applied either after (locally recommended practice or before irrigation. ^{15}N-labeled fertilizers were applied to microplots (1.44 m^2), which were sampled at harvest and analyzed for total and nitrogen isotope ratio.

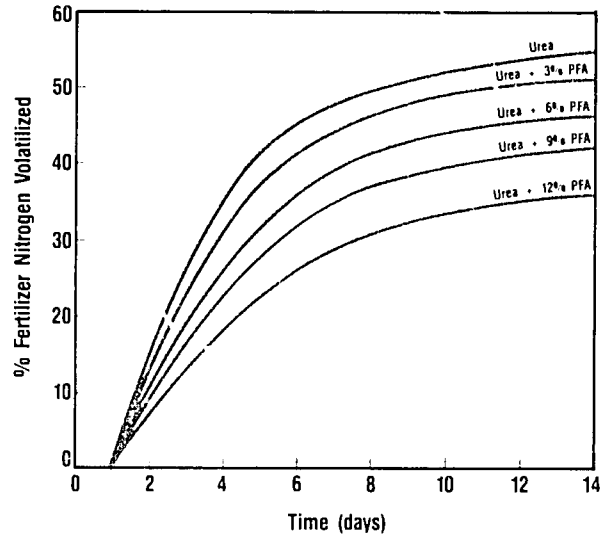


Figure 3. Ammonia Volatilization Losses as Affected by Percent Paraformaldehyde (PFA) Treatment of Urea.

Indian field workers involved in the ICAR/IFDC project take soil samples from ^{15}N-treated microplots.

Yield data of the 1982/83 experiment are shown in Figure 4. Analysis of variance of these data indicated that:

1. There was a highly significant response to applied nitrogen; the agronomic efficiency ranged from 18.7 to 27.4 kg grain per kilogram of nitrogen applied.
2. Topdressed potassium nitrate gave the highest yields in the experiment regardless of whether it was applied before or after irrigation. These results suggested that neither leaching of nitrates nor denitrification was very important under the conditions of the experiment.
3. Timing of irrigation with respect to the topdressing of urea fertilizers had a significant effect on yield. Application of urea before irrigation gave about 22% higher yields than did application after irrigation. This result supported the conclusion that leaching of nitrates was not of major importance and suggested that ammonia volatilization was the principal nitrogen loss mechanism under the conditions of the experiment.
4. Grain yields in treatments where urea-PPD was topdressed after irrigation were about 8% higher than where urea or urea-DCD was topdressed after irrigation. This result supported the conclusion that ammonia volatilization was probably the major nitrogen loss mechanism under the conditions of the experiment and suggested that PPD was effective in reducing these volatilization losses.

Analysis of the ^{15}N data of the experiment confirmed the trends observed in the yield data (Figure 4). Losses of fertilizer nitrogen from the soil-crop system were negligible for potassium nitrate and for urea fertilizers applied before irrigation. These losses were considerable—in the range of 20%-40%—when urea fertilizers were applied after irrigation, whether incorporated or topdressed.

Preliminary results of the 1983/84 collaborative experiments with irrigated wheat in the Punjab seem to parallel the results of the previous season. If further research confirms these results and if the conditions of the experiments are indeed representative of irrigated wheat in this area, then the implications of this research are rather far reaching. For example, in the 1982/83 experiment losses of nitrogen were reduced from about 40% to virtually zero when urea was topdressed before rather than after irrigation. If these results apply to all of the Punjab, the implication is that more than US $24 million worth of nitrogen fertilizer could be saved annually by simply topdressing the urea before irrigation rather than after.

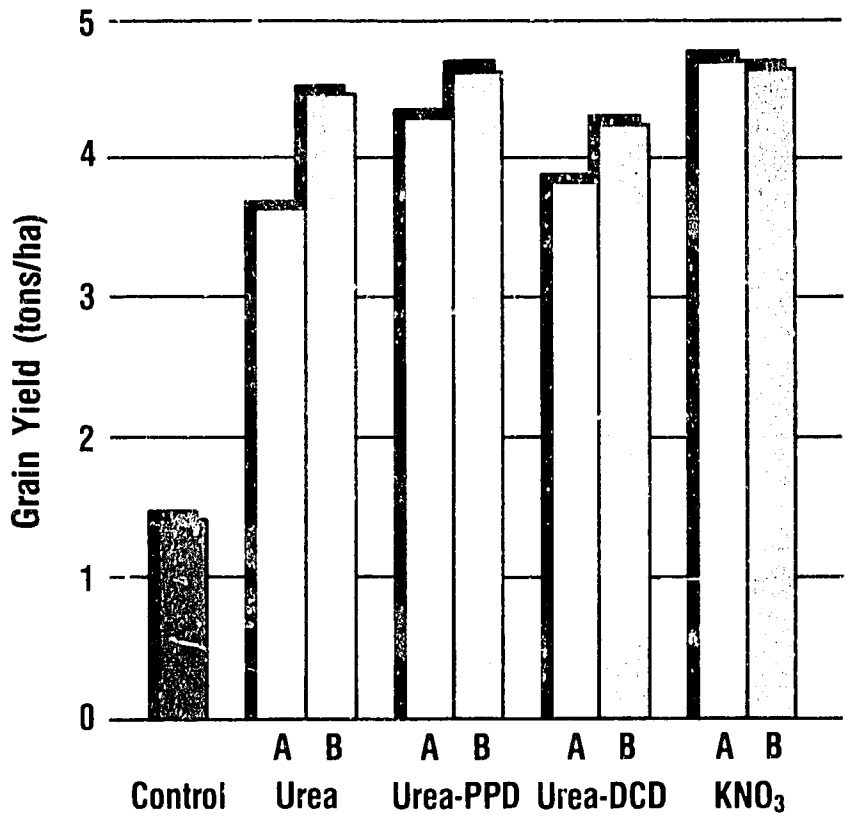


Figure 4. Wheat Yields at Fertilization Rates of 60 kg N/ha Basally Applied and 60 kg N/ha Topdressed After (A) or Before (B) Irrigation..

Fertilizers for Sub-Sahara Africa

Most farmers in Africa have no irrigation facilities. Without a sure supply of moisture, it is often difficult to guarantee a good return in terms of crop yield for money spent on fertilizer. In these countries where funds available for the purchase of fertilizers are invariably limited, it is important to determine which fertilizer products and which time and method of nitrogen application will give the best yields and best economic returns.

In 1982 IFDC established a sub-Saharan African research network to resolve these questions. In 1984 collaborative trials at more than 35 sites were carried out jointly by IFDC staff and the national scientists of 14 countries. Using locally recommended crop varieties and farming practices, IFDC scientists tested varying rates of calcium ammonium nitrate (CAN) or urea, two common fertilizers in Africa, on fields of millet, sorghum, and maize. Time and method of application of these products were also tested. The scientists conducted more intensive trials using these same products enriched with ^{15}N at seven sites in five countries to determine whether the crop was making good use of the

applied nitrogen and whether losses were occurring because of leaching or ammonia volatilization (Figure 5).

Although it is not normally encouraged as a fertilizer management practice, broadcasting of nitrogen fertilizer tended to give better yields in the humid and subhumid zones than did point placement or banding. At a nitrogen application rate of 100 kg/ha in the subhumid area, the yield obtained with broadcasting was approximately 25% higher than that obtained with point placement (Figure 6). In the humid area at the same application rate, the yield increase with broadcasting over point placement was about 7%. In the semiarid sites of Niger, point placement of urea gave poor yields due to large nitrogen losses via volatilization.

Data from ^{15}N trials confirm earlier experimental results, which showed that nitrogen losses are generally low at most sites in the humid and subhumid regions having a seasonal rainfall of 800-1,200 mm. Total recoveries of ^{15}N in 1983/84 ranged from 70%-80% with approximately 50% of that recovered being in the plant itself (Figure 7). In 1982 losses from these zones were less than 10%. Nitrogen recovery by cowpeas, which were intercropped with the maize, amounted to only 2%-3% of that applied. During 1982-84 in the semiarid sites in Niger, losses of fertilizer nitrogen were very high, exceeding 50% when urea was point placed. Here, conditions of light soils, high temperature, and low rainfall have combined to cause nitrogen losses as high as 50% probably due to volatilization. Only 20% of the urea nitrogen that was applied was actually taken up by the plant while plant uptake of calcium ammonium nitrate was 33% (Figure 7).

Future work in Niger will concentrate on nitrogen products and management practices that could reduce these losses, improve uptake efficiency, and increase yields.

Figure 5. IFDC's Nitrogen Research Program in Sub-Saharan Africa.

IFDC's fertilizer research programs aim to place more food on the tables in African homes. Dr. André Bationo, IFDC Soil Scientist stationed in Niger, observes these young children as they thresh sorghum.

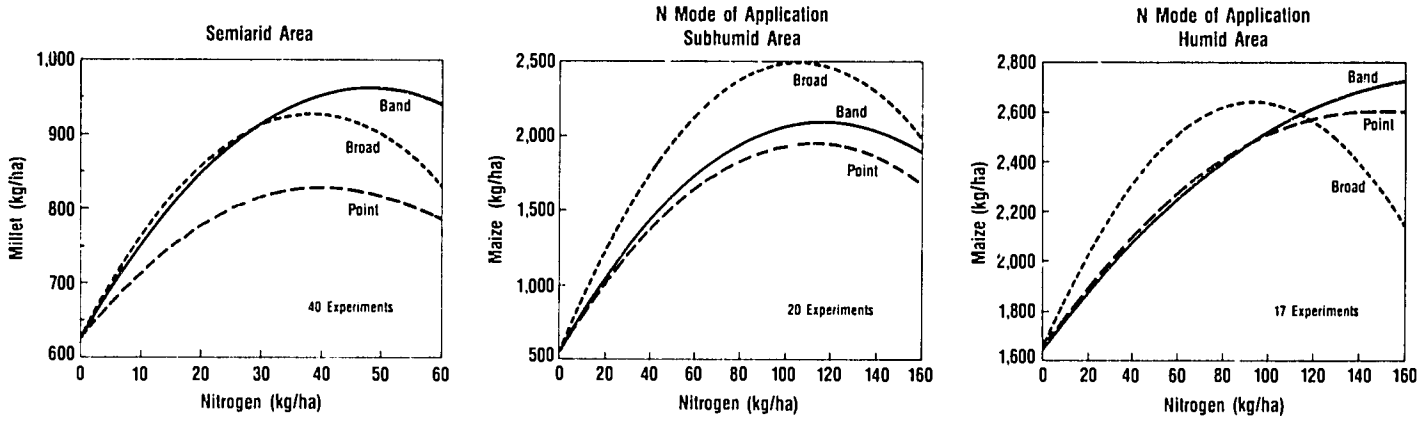


Figure 6. Effect of Method of Application on Yield Response in Various Tropical African Climatic Zones (Response functions are averages of several experiments at various locations during 1982-84.)

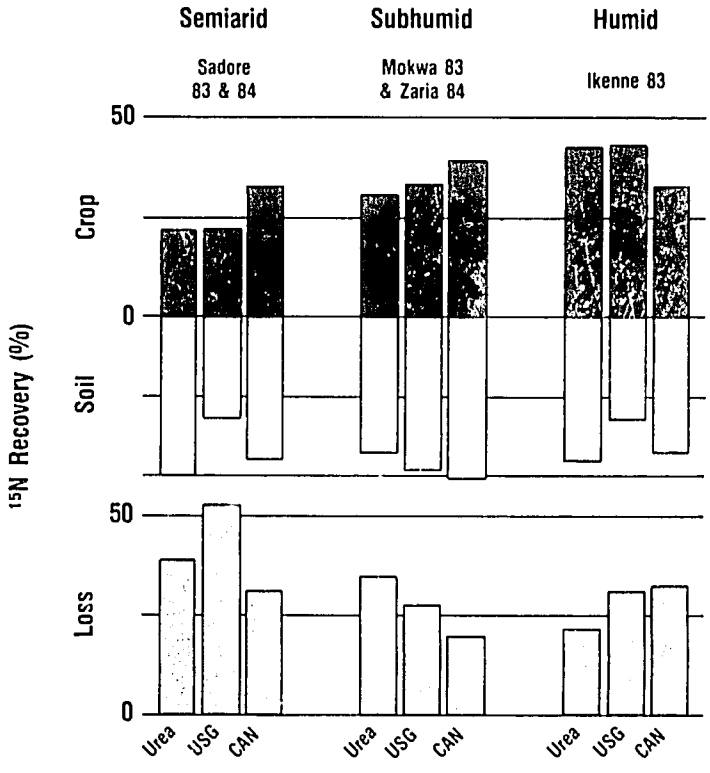


Figure 7. ^{15}N Recovery Fractions in the Crop and the Soil for Three Nitrogen Fertilizer Sources: Urea, USG, and CAN (All fertilizers were split banded.).

In many developing countries of the tropics and subtropics, the earth itself holds a valuable resource—phosphate rock—that can help increase food production. Since IFDC's beginning, the Center's phosphate research program has been dedicated to helping these countries find ways to use their indigenous phosphate resources to produce fertilizer.

Phosphate research involves characterization of the ores, beneficiation of the ores to produce phosphate concentrates, and development of ways to use the concentrate directly as a fertilizer or to chemically modify it. To develop agronomically and economically effective phosphate products, IFDC conducts research in its laboratories and pilot plants. The resulting products are then tested in the Center's greenhouses and fields in developing countries.

During 1984 IFDC furthered its research on several cost-effective approaches to phosphate fertilizer production. For example, additional work was done on partial acidulation. Partial acidulation of phosphate rock offers developing countries a lower cost product since less sulfuric or phosphoric acid is used in its production.

Another cost-saving idea, which was studied, is the process of making a semigranular partially acidulated product rather than conventional granules. This process avoids the expense involved in granulating, recycling, drying, and cooling the product. Comparing the semigranular and granular production schemes, IFDC's fertilizer technologists developed cost estimates of the partially acidulated rock processes. These results will be released in a technical bulletin during 1985.

IFDC produced and evaluated experimental materials from several developing-country phosphate deposits during 1984.

Phosphate Rock Modifications

Beneficiation

IFDC is emphasizing beneficiation studies to remove undesirable magnesium from several phosphate ores. One example is the research conducted on Jhamarkotra (India) ore. Prior laboratory results indicated that a concentrate containing about 36% P_2O_5 and 1% magnesium oxide with a P_2O_5 recovery of 75% could be made from this ore. The feed contained 16.5% P_2O_5 and 11.3% magnesium oxide. In subsequent tests, recovery increased to 80%. During 1984 IFDC used this ore to conduct confirming tests in its continuous beneficiation pilot plant. Results indicated that the concentrate contained 34.5% P_2O_5 and 1.36% magnesium oxide when prepared from a feed containing 16.5% P_2O_5 and 10.9% magnesium oxide. The process involved crushing and grinding to yield an ore feed of minus 48- plus 400-mesh (Tyler); the minus 400-mesh fraction was the slime fraction. Our technologists conditioned the ground ore with phosphoric acid or sodium tripolyphosphate to depress the phosphate. They used a fatty acid or a sulfonated acid to float the dolomite, which was discarded, and discharged the concentrate onto a vacuum filter. During future studies they will process the concentrate to phosphoric acid.

An in-depth laboratory study used another interesting rock type that has a high silica content (Parc W from Niger) to compare flotation beneficiation methods. The feed contained 27.3% P_2O_5 and 28.7% silica. Three flotation methods were used: (1) anionic, (2) reverse anionic, and (3) cationic. Results are tabulated below.

Ibezim J. Anazia, Minerals Engineer, conducts laboratory flotation tests of Jhamarkotra ore from India. These tests served as the basis for large-scale pilot-plant tests.

Flotation Method	Concentrate Grade		Recovery in Concentrate	
	P_2O_5	SiO_2	P_2O_5	SiO_2
	- - -(wt %)- - -		- - - -(%)- - -	
Anionic	30.1	20.2	82.5	60.1
Reverse anionic	30.4	19.4	83.0	55.5
Cationic	32.5	14.1	69.7	33.7

In anionic flotation, a sulfonated fatty acid is used to float phosphate particles in the froth, and silica remains in the cell; sodium silicate at pH 8 is used as a silica depressant. In reverse anionic flotation, a sulfonated fatty acid is used to float silica, and pearl starch is used to depress phosphate in the cell. In cationic flotation, an amine or its salt is used to float the silica at a neutral pH. The cationic flotation yielded the highest grade (32.5% P_2O_5) but lowest P_2O_5 recovery (69.7%).

Single-Step Process for Partial Acidulation Granulation

Using readily available central Florida and Vernal, Utah, phosphate rocks, IFDC fertilizer technologists produced partially acidulated-granulated rock employing sulfuric acid in pilot-plant tests to confirm prior laboratory-scale results. The major process parameters studied were degree of acidulation, concentration of acid, and process temperature profile. The two rock sources were chosen because they had medium reactivity (Florida) and low reactivity (Utah) and were the lowest cost sources available. The typical production rate of product was 250 kg per hour, but some runs were made at 750 kg per hour. Results indicated that the process is relatively simple and easy to operate and can accommodate changes in the degree of acidulation and concentration of sulfuric acid. The process does not require major changes in the operation of the plant, and the physical quality of the product is similar to that of single superphosphate (SSP). There were differences noted between operation with the two rocks although both could be used satisfactorily. To make a thorough comparison of phosphate rock sources, further tests in the pilot plant are needed.

In laboratory-scale tests of the single-step process, rocks containing more than 5% carbon dioxide, which evolves during acidulation, presented difficulties. When these rocks are used, a preacidulation step is required to avoid production of porous and weak granules. A similar problem is expected in larger scale equipment. IFDC staff developed a process flow diagram and a description of the major equipment items for a 10-tph single-step partially acidulated phosphate rock (PAPR) plant. IFDC also plans to conduct economic studies of the process.

Modeling of Wet-Process Phosphoric Acid

A significant continuing activity of phosphate research is to evaluate phoshate rocks in developing countries for making wet-process phosphoric acid. These unknown rocks are compared with commercially available sources. IFDC developed a model and computer program in BASIC for heat and material balance calculations of the dihydrate phosphoric acid process. Data inputs that are required include: chemical analysis of the rock, process conditions, and some process assumptions. The model is helpful in predicting process flow rates and concentrations to be used during startup; thus, the time for reaching equilibrium conditions is reduced. The model is applicable to IFDC's bench-scale and pilot-scale units and operable on some personal computers.

The bench-scale wet-process phosphoric acid unit has been mainly operated in the dihydrate mode. Some modifications were made to the acidulation unit to broaden its capability. In some tests a two-stage reactor system, a complete scrubbing system for the reactors and filter, and a rock-slurry feed (to simulate wet rock grinding) were used. One complete test was made in the hemihydrate mode of operation. The continuous concentrator based on vacuum evaporation was used to produce merchant-grade acid (54% P_2O_5). Examples of some results are given under "Special Research and Development Projects."

Rock Characterization

A significant effort was devoted to 12 phosphate samples submitted by Zambia's Department of Agriculture. The country is interested in the materials as a phosphate and/or lime source. The samples are fairly complex combinations of minerals (Table 1). The Chilembwe rock and Nkombwa soil samples have P_2O_5 levels that might justify beneficiation. The other two samples may be useful as liming sources. Phosphate availability in all samples may be relatively low as indicated by the low solubility in neutral ammonium citrate.

Preparation of Experimental Materials

To support the agronomic research program, the Fertilizer Technology Division produced several experimental fertilizer materials using various rock sources. Examples of rock sources used include Togo, Sukulu Hills (Uganda), Tilemsi Valley (Mali), Dorowa (Zimbabwe), and Kodjari (Burkina Faso), as shown in Table 2. The technologists used sulfuric acid in the IFDC single-step partial-acidulation granulation process to produce granular products. The degree of acidulation of a given rock determines the available P_2O_5 (water-soluble + neutral ammonium citrate-soluble P_2O_5) in the product. The actual values, however, also depend on the reaction conditions and impurities in the rock. The PAPR products are intended for use only on acid soils. The level of acidulation indicates the quantity of sulfuric acid used compared with that required to make SSP. Much of

Table 1.
Principal Characteristics of Zambia Phosphate Rock Samples

Source	Average Values: Total P_2O_5	Average Values: Citrate-Soluble P_2O_5	Major Mineral Phases
	- - (wt %) - -		
Chilembwe phosphate rock	16.0	1.3	Apatite, augite, magnesioriebeckite
Nkombwa soil	13.2	0.9	Hematite-goethite-magnetite, apatite, quartz, braunite
Nkombwa phosphate rock	3.7	0.3	Dolomite, hematite-goethite, apatite
Kaluwe phosphate rock	3.2	<0.1	Calcite, hematite-goethite-magnetite, apatite

Table 2.
Analysis of Typical Rock Sources and PAPR Products

Rock Source	Rock Analyses: Total P_2O_5	Acidulation Level[a]	PAPR Product Analyses: Total P_2O_5	Available P_2O_5[b]: Total	Available P_2O_5[b]: % of Total
	(wt %)	(%)	(wt %)	(wt %)	
Togo rock	35.9	-	-	-	-
Togo PAPR	-	25	28.6	7.8	27.3
Togo PAPR	-	50	24.2	12.5	51.7
Sukulu Hills rock	37.3	-	-	-	-
Sukulu Hills PAPR	-	50	25.3	14.6	57.7
Sukulu Hills SSP	-	100	22.2	21.0	94.6
Tilemsi Valley rock	28.6	-	-	-	-
Tilemsi Valley PAPR	-	15	26.0	6.5	25.0
Tilemsi Valley PAPR	-	30	22.7	11.0	48.5
Dorowa rock	33.1	-	-	-	-
Dorowa PAPR	-	25	24.8	7.5	30.2
Dorowa PAPR	-	50	23.0	10.0	43.5
Kodjari rock	25.3	-	-	-	-
Kodjari PAPR	-	30	20.3	5.8	28.6
Kodjari PAPR	-	50	18.1	8.7	48.1

a. Percentage of sulfuric acid required to fully acidulate the rock to single superphosphate.
b. Sum of water-soluble and neutral ammonium citrate-soluble P_2O_5.

IFDC's work is conducted at the 50% acidulation level.

Improved Research Capabilities

To the extent possible IFDC updates its research capability through equipment modifications and additions. This section briefly describes some improvements made this year.

Ion Chromatograph

During 1984 IFDC acquired an ion chromatograph to analyze for certain ions. Applications of the ion chromatograph include the determination of fluoride and sulfate in phosphate rocks, wet-process phosphoric acid, and fertilizers. It is also used to determine the level of sulfates and nitrates in soils.

Image Analysis System

Another new capability was added with the development of an image analysis system. This system consists of a research-grade optical microscope coupled with a high resolution video camera and screen. The system is interfaced with computer graphics and a digitizer board. The image analysis system provides functions such as distance measurements, areas, volumes, form factor analysis, point counting, spatial frequency, and angle measurements. A statistical package is an integral part of the system. Data may be displayed as linear, logarithmic, or percentage of total as histograms. The system is particularly useful in determining crushing sizes of phosphate ores and is also being used to evaluate gypsum crystal morphology from wet-process phosphoric acid production.

Steven Van Kauwenbergh, IFDC Mineralogist, uses an image analyzer to determine the particle size, range, and shape of minerals in phosphate ores.

Agronomic Research in Laboratories and Greenhouses at Headquarters

Phosphorus Soil Test

Efficient use of phosphate fertilizers in soils requires a basic understanding of the chemical properties of phosphate fertilizers, their reactions with soils, and their interactions with other nutrients in soils. By conducting basic studies in Headquarters' laboratories and greenhouses, IFDC soil scientists have collected information that is relevant to agronomic trials of phosphate fertilizers under tropical and subtropical field conditions.

In 1984 IFDC soil scientists worked on a new technique to predict the amount of plant-available phosphorus in soils; this information is needed to make fertilizer recommendations. In using this method, the soil sample is shaken in water containing a strip of porous paper impregnated with amorphous iron hydroxide. The paper adsorbs the phosphorus in the soil solution. The paper is then removed, and the phosphorus on it is extracted with dilute acid and measured. The results obtained from pot trials show that this method is suitable for estimating plant-available phosphorus.

The new method has several advantages over the ones now in use. The paper does not affect the soil itself; yet, it adsorbs the phosphorus in the soil solution. Therefore, the paper can be used to extract phosphorus from all types of soils regardless of soil properties or the nature of the fertilizer applied. The method simulates the absorption of phosphorus by plant roots and is therefore likely to give a more representative measurement of available phosphorus than other analytical procedures. In tropical soils having very low concentrations of soluble phosphorus, the new method may give a more reliable estimate of available phosphorus.

Nitrogen-Phosphate Rock Fertilizers

Many tropical and subtropical soils require phosphorus as well as nitrogen fertilizers for crop production. Where direct application of phosphate rock is being considered, a means of enhancing the availability of phosphorus should be studied. Previously, IFDC soil scientists found that urea mixed with phosphate rock may increase phosphate rock dissolution in soils having a high organic matter content. Supposedly, urea hydrolysis in soil temporarily raises the soil pH and hydrolyzes the soil organic matter, which then chelates calcium ions and hence provides a driving force for the dissolution of phosphate rock.

In 1984 IFDC soil scientists conducted several greenhouse trials to determine if urea would have a beneficial effect on plant-available phosphorus from phosphate rock. In one trial with an acid Bladen sandy loam (pH 4.5), which contained about 2% organic matter, the dry-matter yield of maize obtained with powdered Sechura phosphate rock from Peru mixed with urea increased by about 230% as compared with mixing it with ammonium nitrate. In this study, nitrogen was not a limiting factor when the two sources of nitrogen fertilizers were compared. In another greenhouse trial with neutral Josephine sandy loam (pH 6.2), which contained about 5% organic matter, minus 35-mesh mixtures of Sechura rock and urea or mixtures of rock and ammonium chloride were studied for their phosphorus availability. Urea was more effective than ammonium chloride in increasing the availability of Sechura rock (Figure 8). When the phosphorus rate was 100 ppm, the addition of 200 ppm nitrogen as urea increased the dry-matter yield of maize almost twice as much (176%) as when the same amount of nitrogen was added as ammonium chloride. Future field trials are being planned for areas with soils derived from volcanic ash, which usually contain relatively high amounts of organic matter.

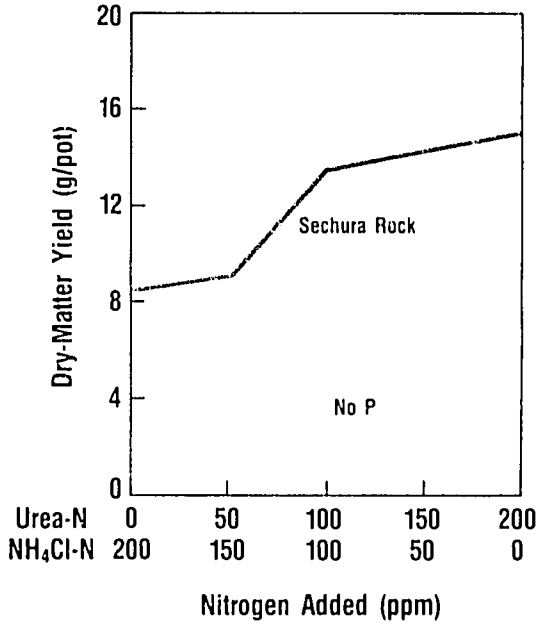


Figure 8. Dry-Matter Yield of Maize Obtained With Phosphorus and Nitrogen Fertilizers in a 6-Week Greenhouse Study (rate of P = 100 ppm).

Partially Acidulated Phosphate Rock

Previous work at IFDC has shown that many west African phosphate rocks are low in chemical reactivity and therefore unsuitable for direct application on short-season crops. In 1984 IFDC soil scientists evaluated the agronomic effectiveness of PAPR products made by acidulating Kodjari phosphate rock from Burkina Faso (formerly Upper Volta) with 20% to 50% of the sulfuric acid that would have been required to produce SSP. The purpose of the study was to screen potential products for field trials. Powdered Kodjari rock is indeed low in reactivity and thus may not be suitable for direct application (Figure 9). Acidulation of the rock with only 20% of sulfuric acid greatly improved its agronomic effectiveness; at a phosphorus application rate of 100 ppm as 20% PAPR the dry-matter yield of maize per pot was about six times as great as the yield with phosphate rock alone. Increasing the degree of acidulation from 20% to 50% only gradually increased the dry-matter yield of maize. Although commercial SSP resulted in the highest yield, a mere 20% acidulation of the rock gave an agronomic value that was almost 50% as good as that of SSP. The cost of PAPR is reduced by a decrease in the amount of acid required for its production. Therefore, the economic value of 20% PAPR in this trial is enhanced by the substantial reduction in the amount of sulfuric acid required in its production.

Since the Kodjari rock is known to be unsuitable for making SSP because of its poor quality, production of a PAPR granular product by the IFDC-developed single-step process should be a potential route whereby Burkina Faso can use its indigenous rock if other factors are favorable. Production of run-of-pile (ROP) PAPR at the 50% acidulation level resulted in a product as agronomically effective as the granular PAPR (Figure 9). This is a significant finding since ROP PAPR is considerably cheaper to produce than the granular product.

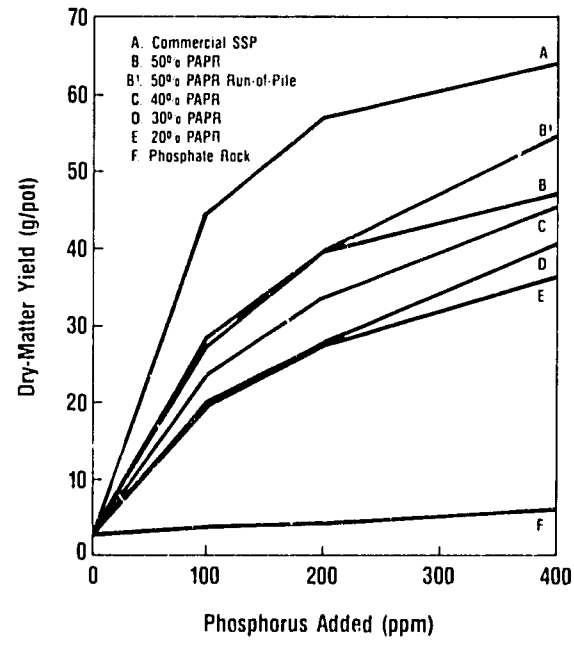


Figure 9. Dry-Matter Yield of Maize Obtained With PAPR Made From Kodjari Phosphate Rock From Burkina Faso in a 6-Week Greenhouse Study. (Commercial SSP was used for comparison.)

Agronomic Field Research—Latin America

Suitability of Indigenous Phosphates

An intensive 2-year farm-level evaluation of phosphate materials derived from Colombian phosphate rocks was completed in June 1984. The overall objective of the research was to evaluate the agronomic effectiveness of phosphorus fertilizer alternatives, based on low-cost indigenous raw materials, with a high probability for availability, competitiveness, and farmer acceptance.

The project, coordinated from the facilities of Centro Internacional de Agricultura Tropical (CIAT) in Palmira, Colombia, focused on farm-level experimentation with finely ground and partially acidulated rock. In collaboration with the Instituto Colombiano Agropecuario, a series of trials was established in three different agroclimatic zones typically found in Latin America: midaltitude, highland, and lowland tropics. The first year's results were reported in the *1983 IFDC Annual Report*. Averaged findings for the 2-year multilocational trials follow.

On-Farm Evaluations

Beans Grown in Cauca—Triple superphosphate (TSP) and PAPR were both highly effective in increasing bean production, and no significant difference between them was observed. Both were significantly more effective than finely ground Huila phosphate rock applied directly during the initial cropping period. In the second cropping period, the effectiveness of the Huila phosphate rock increased. While it remained significantly less effective than both TSP and PAPR in terms of accumulative production, its effectiveness was similar to that of PAPR during the second crop. On an average, Huila phosphate rock was 38% and 78% as profitable as TSP for the two crops, respectively, while PAPR made from Huila rock (using only half of the acid required to make superphosphate) was 92% and 79% as profitable as TSP for the two crops. The reduced effectiveness of the Huila phosphate rock in this midaltitude zone is attributed to the high phosphorus fixation by the soil, the use of point placement by the farmers, and the short duration of the growing season of beans.

Maize/Beans Associations in Nariño—Contrary to the results obtained in Cauca with beans alone, averaged results in Nariño showed that all three sources (TSP, PAPR, and Huila phosphate rock) were equally effective agronomically when used in a maize/bean association. The increase in effectiveness observed with Huila phosphate rock is attributed to the lower phosphorus fixation by the soils in Nariño and the fact that the life cycle of crops is longer in the highlands of Nariño than in the midaltitudes of Cauca. As an example, in Nariño climbing beans mature in 9 months as compared with 3 months for bush beans in Cauca. This allows additional time for uptake of phosphorus from the slowly dissolving phosphate rock.

Potatoes in Nariño—The average response observed with potatoes to the different phosphate fertilizers applied was similar to that observed with beans in Cauca, i.e., in the first crop, there was no significant difference between TSP and PAPR, but both were superior to Huila phosphate rock. The effectiveness of Huila phosphate rock in the second crop (residual effect) was equal to that of the other sources, but the accumulative two-crop yield was still significantly lower (only about one-fifth of that of partially acidulated Huila phosphate rock) (Figure 10). These results were obtained despite the low phosphorus-fixation capacity of the soil because of the high initial requirement for phosphorus by potatoes, which the phosphate rock was not able to satisfy.

Rice in Meta—While there was considerable variability in the agronomic

A Colombian farmer participates in planting a farm trial being conducted by IFDC to evaluate phosphate rock fertilizer.

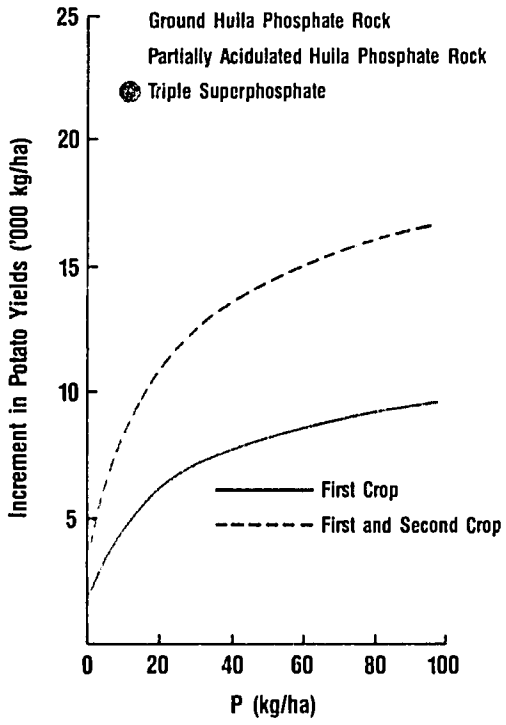


Figure 10. Initial (first crop) and Accumulative (first and second crop) Effects of Phosphorus Sources and Rates on Potato Yields in Ipiales, Nariño, Colombia.

effectiveness of the different fertilizer products among sites in this lowland zone, average yields show that there was no significant difference between TSP and PAPR for either rainfed or irrigated rice. The ground phosphate rocks (Pesca and Huila) were 78% and 72% as effective as TSP, respectively, with the flooded rice, but were ineffective in the rainfed rice experiments. The phosphorus levels in the soil were relatively high and the main influence of the soluble sources was apparently that of a starter effect, which was not obtained with the phosphate rocks.

In general, the results obtained in these and other evaluations indicate that PAPR prepared from local resources can be equally as effective as the soluble commercial fertilizers across a wide range of acid soil types and for a wide range of cropping systems. Unacidulated phosphate rock, however, has a much narrower range of applicability, both in terms of soils and cropping systems. A new phase of research was, therefore, initiated in 1984 to identify improved means of managing phosphate rock for use under unfavorable conditions.

Agronomic Field Research—Africa

In 1984 the effect of a 3-year drought worsened the food shortage and threatened the lives of millions of people in sub-Saharan Africa. Long-term solutions are needed to promote self-sufficiency in food production in sub-Saharan Africa. Agricultural research is an important aspect of these solutions. Against this background the IFDC's Africa Fertilizer Research program, which entered its third year of operation in 1984, took on added significance.

During 1984 several of the earlier experiments that were undertaken to evaluate the agronomic effectiveness of different phosphorus fertilizer sources, including indigenous phosphate rocks, were continued. New field trials were established in Gambia, Sierra Leone, Liberia, and Cameroon. In Nigeria, Niger, Togo, and Kenya the program was expanded to cover more ecological zones. In addition to evaluating phosphorus fertilizer sources, experiments were carried out to develop management practices for more efficient use of phosphorus fertilizers.

Regardless of the agroecological zone, phosphorus application resulted in significant increases in grain yield. The significant response to phosphorus fertilizers at all locations lent credence to earlier observations that soils of tropical Africa are phosphorus deficient. Phosphorus requirement for optimum maize production varied from a high of 140 kg P_2O_5/ha in an Ultisol at Njala (Sierra Leone) to a low of 40 kg P_2O_5/ha in an Alfisol at Sapu (Gambia). Response to phosphorus was stronger in the drier ecosystems than in the more humid forest zones. This is illustrated by the data in Table 3 showing the phosphorus efficiency index for maize at different locations.

Finely ground Togo phosphate rock for direct application was evaluated at different locations in Togo, Sierra Leone, and Nigeria. In the Ultisols in

Table 3.
Phosphorus Efficiency Index[a] for Maize at Different Locations

	Rainfall	Yield With No P Added	P Required for Maximum Yield	Maximum Yield	P Efficiency Index
	(mm)	(kg/ha)	(kg P_2O_5/ha)	(kg/ha)	(kg grain/kg P_2O_5)
Njala, Sierra Leone (humid)	1,600	1,271	142.8	2,291	7.14
Sarakawa, Togo (subhumid)	1,200	771	64.7	2,280	23.32
Sapu, Gambia (semiarid)	-	447	45.6	1,404	21.32

a. Phosphorus efficiency index = $\frac{\text{maximum yield—yield with no phosphorus added}}{\text{maximum phosphorus applied for maximum yield}}$

Nigeria and Sierra Leone where the soils were very acid and moisture was not a limiting factor, the relative agronomic effectiveness (RAE) of Togo phosphate rock, using SSP as the standard and maize as the test crop, was 47%. However, in the Alfisols in the subhumid zones of Nigeria and Togo, the RAE was only 25%. Similarly, directly applied finely ground Parc W phosphate rock was evaluated at several locations in Niger using millet as a test crop. In 1982 and 1983 when moisture was adequate, the RAE averaged 50%; in 1984 when the lack of moisture limited crop growth, the RAE dropped to 27%. The soils in Niger are sandy soils with low phosphorus, calcium, oxalate-extractable iron, and aluminum. These conditions tend to promote dissolution of phosphate rock as well as efficient use of solubilized phosphorus from phosphate rock by crops. At Sapu in Gambia during the dry year 1984, the relatively reactive Tilemsi phosphate rock from Mali was 62% as effective as SSP.

Partial acidulation of the west African phosphate rocks improved their initial agronomic effectiveness (Figure 11). Over the last 3 years, 50% PAPR was, on the average, 95% as good as the superphosphates across all ecological zones. At several locations in Nigeria, trials were conducted to compare 50% Togo PAPR with SSP, diammonium phosphate (DAP), and 15-15-15, which were the commercially available fertilizers in Nigeria. In locations where sulfur was limiting crop growth, 50% PAPR was as good as SSP and superior to DAP and 15-15-15. At an application rate of 40 kg P_2O_5/ha the 50% PAPR produced about twice as much maize per hectare as did DAP or 15-15-15. The reason for the poor performance of DAP and 15-15-15 is the absence of sulfur in these commercial fertilizers. Figure 12 shows the response that is typical of all locations. These results indicate the need to identify areas of sulfur deficiency before recommending high-analysis fertilizers free of sulfur.

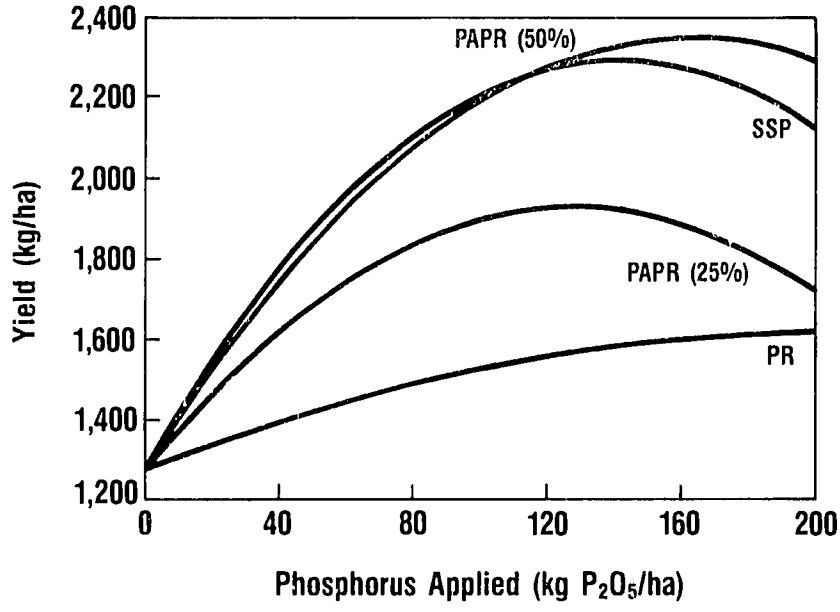


Figure 11. Effect of Phosphorus Rate and Source on Maize Grain Yield in the Humid Area (Njala, Sierra Leone, 1984). (The phosphate rock used in this experiment is Togo phosphate rock.)

African farmers who use granular fertilizers generally broadcast these materials onto the soil surface. IFDC scientists in Niger established a trial to compare various methods of phosphorus fertilizer application. For best results, granular phosphorus fertilizer should be broadcast and incorporated in these phosphorus-deficient sandy soils. Point placement of fertilizers was the least productive.

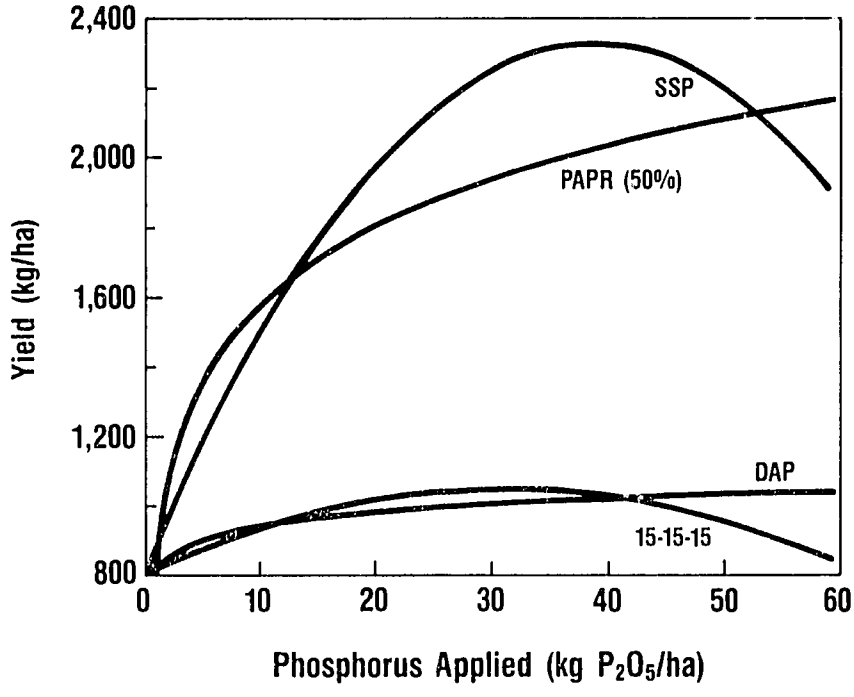


Figure 12. Performance of Different Phosphate Fertilizers in Soils Where Sulfur is Limiting Maize Yield in Nigeria.

Special Research and Development Projects

A number of special research projects were carried out. These activities included ore characterization, acidulation, and granulation and were carried out in laboratories, pilot plants, and greenhouses. Brief summaries are given in this section.

Studies of Mussoorie Rock From India

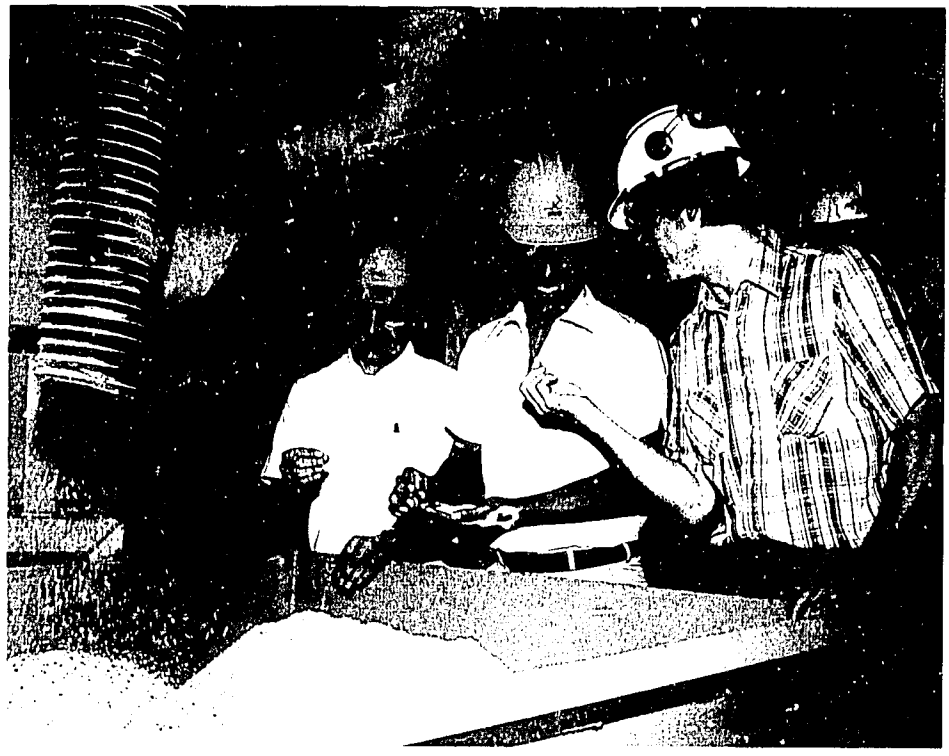
Under contract with Pyrites, Phosphates and Chemicals, Ltd. (PPCL), IFDC completed a special study of the use of Indian Mussoorie phosphate rock as fertilizer. A complete characterization of the rock was made through chemical, mineralogical, and textural analyses. Acid-type attrition scrubbing was investigated as a method of reducing the carbonate content. Two granulation routes—minigranulation and granulation with partial acidulation—were evaluated. Various salt binders were used in the production of minigranulated materials in a pinmixer. Using sulfuric or phosphoric acid in the IFDC single-step process, the fertilizer specialists partially acidulated run-of-mine ore and the concentrate.

Various experimental products were evaluated in the IFDC laboratory and greenhouse. This testing indicated that the most promising products for Indian acid soils were those made by partial acidulation (sulfuric or phosphoric acid), rather than the minigranulated rock. Further field trials in India are being made to verify these preliminary results. The economics of production and use in India are being developed by PPCL. All of these data are being factored into activities to be conducted during 1985.

Granulation of Urea-Based Multinutrient Fertilizer for Mexico

Fertilizantes Mexicanos, S.A. (FERTIMEX) of Mexico is modifying an original granular TSP plant located near Coatzacoalcos (Veracruz) to produce DAP and urea-based NPK such as 17-17-17 (N-P_2O_5-K_2O). Granulation is carried out in a pug mill-type granulator. IFDC configured its pilot plant to simulate the FERTIMEX unit and conducted tests of 17-17-17 production. Raw materials used were phosphoric acid, sulfuric acid, ammonia, urea, potassium chloride, and ammonium sulfate. A preneutralizer was used for reactions of ammonia with phosphoric and sulfuric acids. Urea and potassium chloride were added as solids. To produce the required grade, IFDC's chemical engineers studied a number of options including combinations of solid ammonium sulfate and that produced *in situ*. The effects of several operating parameters were determined. Using IFDC pilot-plant results, the engineers calculated the potential daily capacity of the FERTIMEX plant. Two FERTIMEX engineers assisted in conducting the tests and accompanied an IFDC engineer to a commercial NPK plant in the southern part of the United States.

Results indicated that multinutrient fertilizers based on urea can be successfully produced in the FERTIMEX plant.



Ing. R. Sergio Torres Osorio (left) and Ing. Agustin Escalante M. of FERTIMEX, with IFDC Special Project Engineer Jose R. Lazo de la Vega, examine urea-based NPK product in the IFDC Pilot Plant.

NPK Granular Fertilizer for Malaysia

At the request of the Chemical Company of Malaysia Berhad (CCM), IFDC completed a study on the production of urea-based NPK fertilizers in continuous laboratory-scale equipment. To determine modifications required for the conversion of CCM's commercial plant from ammonium nitrate-based NPK to urea-based NPK production, IFDC evaluated the effect of various raw material combinations and process conditions.

IFDC recommended modifications to the CCM plant to enable them to produce urea-based NPK fertilizers.

Studies of Bahia Inglesa Phosphate From Chile

During 1984 IFDC completed the preliminary project to characterize and beneficiate phosphate ore from the Bahia Inglesa deposit in Chile. On the basis of laboratory results our engineers developed a beneficiation process for removal of impurities, such as silica, iron, aluminum, and magnesium. IFDC recommended further larger scale tests to confirm these initial findings and to evaluate more fully the effect of using seawater versus fresh water for the flotation process. The sponsor will determine the extent of the deposit's reserves prior to conducting further research work.

Studies of Uganda Phosphate

IFDC characterized igneous phosphate ore from the Sukulu Hills region of Uganda, including various flotation fractions. This country is considering reopening its phosphate mine and renovating its SSP production facility. The ore contains iron, an impurity that may affect the processing and the chemical and physical quality of the product. IFDC evaluated the use of the ore for SSP production. In addition, our engineers compared two routes for making a partially acidulated product from Uganda concentrate using sulfuric acid. They made comparative tests of the product's physical and chemical qualities. They also evaluated the compatibility of mixtures

of partially acidulated products with urea, ammonium sulfate, and calcium ammonium nitrate. Bulk blending is one method of incorporating multinutrients into fertilizers sold in the market area.

A longer range strategy of the country may involve the use of Uganda phosphate concentrate to produce wet-process phosphoric acid and conversion to TSP or ammonium phosphates (MAP/DAP). IFDC converted the concentrate to phosphoric acid and produced granular TSP and MAP/DAP in continuous laboratory-scale equipment.

IFDC's investigations proved that Uganda phosphate rock can be used to produce SSP and PAPR.

Compaction-Granulation of Multinutrient Fertilizer for Malaysia

Under contract with Peladang Kimia Sendirian Berhad in Malaysia, IFDC used the laboratory-scale compactor to study various NPK formulations, with and without magnesium. Nitrogen sources were urea, ammonium sulfate, and ammonium chloride. Phosphate sources were diammonium phosphate and ground phosphate rock. Muriate of potash and sulfate of potash magnesia were also used. IFDC fertilizer technologists conducted tests to study the relative compactibility, granule characteristics, and granulation efficiency. IFDC provided a conceptual flowsheet for a commercial plant (30 tph) and supplied an estimate of the necessary plant investment to the company for discussion with commercial equipment suppliers.

Peladang Kimia is considering this strategy for altering its production scheme in the future.

The increasing occurrence of sulfur deficiency in tropical agriculture is primarily caused by the increased use of high-analysis essentially sulfur-free nitrogen and phosphate fertilizers such as urea, DAP, and TSP in conjunction with more intensive cropping with high-yielding varieties. Moreover, soils in the tropics generally have low total sulfur contents because of low sulfur-bearing parent materials and/or extreme weathering and leaching losses. Because the sulfur deficiency in tropical agriculture is increasing, it is urgent that developing countries consider including sulfur in their fertilizer programs.

Transportation and handling costs often dictate a preference for high-analysis fertilizers. Consequently, elemental sulfur, which is the most concentrated form of the element (100% sulfur), may be the preferred choice to be added to existing nitrogen and phosphate fertilizers to avoid diluting these nutrients in the fertilizer and increasing shipping and handling costs per unit of nutrient. However, elemental sulfur will become available to plants only through oxidation to sulfate by microorganisms in the soil. During 1984 IFDC soil scientists conducted laboratory and greenhouse studies at Headquarters to evaluate the potential use of elemental sulfur mixed with nitrogen and/or phosphate fertilizers as a sulfur source for crop production.

A soil incubation experiment was conducted to study the effect of nitrogen and/or phosphate fertilizers on the rate of sulfur oxidation in soils. The fertilizers studied were MAP, DAP, TSP, urea phosphate (UP), and urea. Preliminary results indicated that both nitrogen and phosphate fertilizers enhanced the rate of sulfur oxidation in two soils (Figure 13). For example, when DAP was added, the amount of elemental sulfur that was oxidized was almost twice as great as when no nitrogen or phosphate fertilizer was used. Future work will examine the effect of N:P:S ratio, granule size, and soil moisture, temperature, and chemical properties that may affect the rate of sulfur oxidation in soils.

There are increasing indications of sulfur deficiency in rice-growing soils of many developing countries. Using a combination of nitrogen and sulfur fertilizers for flooded rice, IFDC soil scientists conducted a greenhouse study during 1984 to evaluate the efficiency of fertilizers in which elemental sulfur was derived from a commercially available urea-sulfur source. They found that the agronomic effectiveness of the urea-sulfur as a sulfur fertilizer was influenced by the particle size of the fertilizer material and the method of application (Figure 14). For surface broadcasting and broadcasting with incorporation, powdered urea-sulfur performed as well as gypsum, and both were better than prilled urea-sulfur. Although the sulfur particles imbedded in the prilled urea-sulfur melt were very small (minus 100-mesh), sulfur oxidation was apparently decreased because of a reduction in the amount of physical contact of sulfur particles with the soil environment. Deep placement greatly reduced the effectiveness of elemental sulfur in the urea-sulfur melt regardless of whether it was powdered or prilled.

Although surface broadcasting of prilled urea-sulfur melt is a feasible means of applying sulfur fertilizer for flooded rice at transplanting, IFDC research has shown that the method can lead to serious nitrogen losses through ammonia volatilization. While deep placement of the urea-sulfur would greatly reduce these losses, the reduced rate of sulfur oxidation would render the elemental sulfur component ineffective in supplying sulfur nutrient, particularly at the early stage of rice growth when the rhizosphere influence is minimal. IFDC continues to conduct research at Headquarters to find a means of supplying sulfur to flooded rice.

Urea-Based Granular Fertilizers

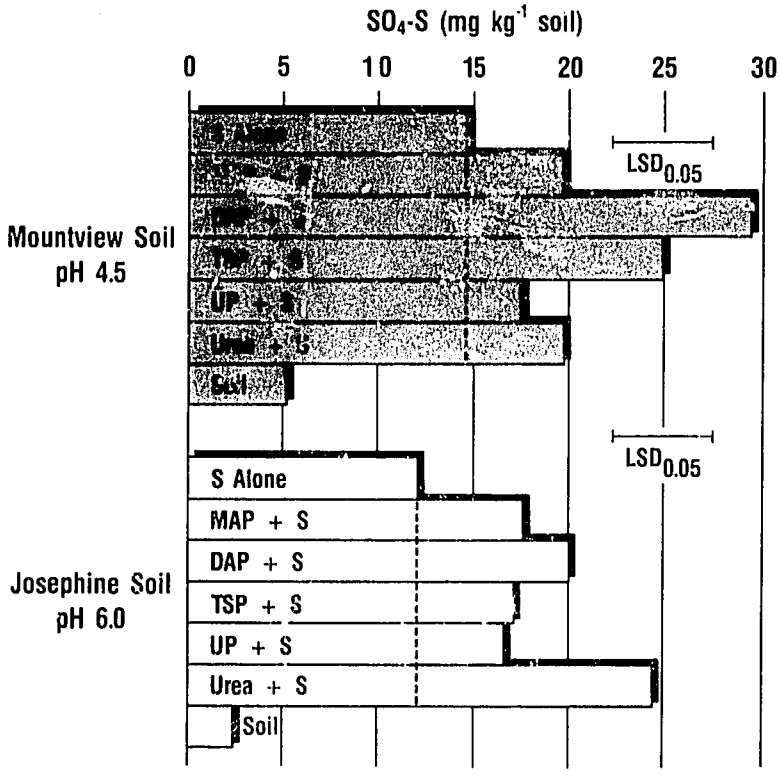


Figure 13. Effect of Sources of Phosphorus (MAP, DAP, TSP) and Nitrogen (UP, Urea) on Oxidation of Elemental Sulfur at a Rate of 200 mg S kg-1 Soil After 1-Week Incubation in Two Soils. (The ratios of N:S and P:S were fixed at 1:1.)

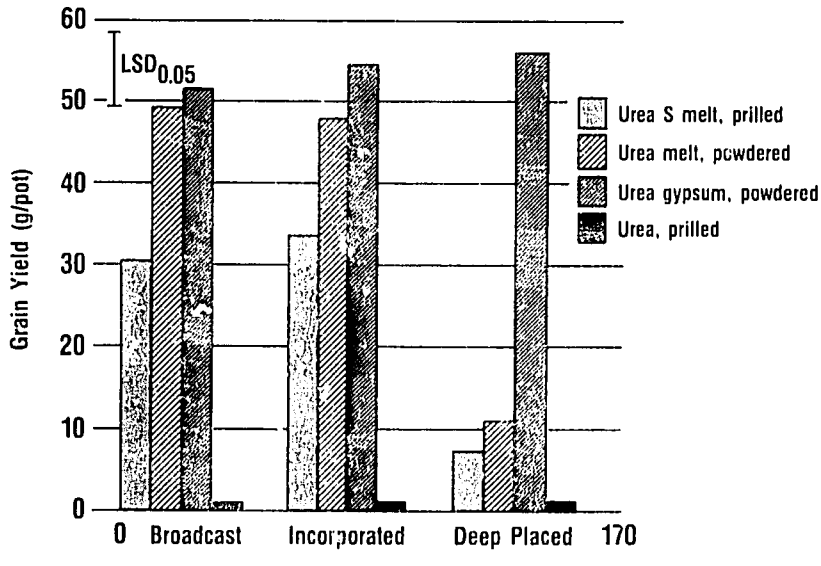


Figure 14. Rice Grain Yield Response to Sulfur Fertilizer Materials as Influenced by Placement Method (30 kg S/ha).

In most developing countries urea is the important nitrogen source whether it is used alone or in mixtures with other nutrients. Commercial technology is rapidly emerging for granulation of urea, and some new plants presently under construction will use granulation rather than prilling. Whether the urea is granular or prilled, it will continue to be a prime source of nitrogen, and suitable means must be found to combine it with other nutrients to make compound fertilizers that also contain phosphorus and potassium, with and without micronutrients.

IFDC is identifying suitable methods for making compound fertilizers that contain large quantities of urea. Urea-based NPK fertilizers require special treatment during production, storage, and handling under tropical conditions.

Depending on the type of raw materials available in a particular country, there are several process alternatives for producing urea-based NPK fertilizers. Urea can be added as dry prills, granules, solution, melt, or some combinations of these. Phosphate can be derived from several sources—ground phosphate rock, PAPR, superphosphate, phosphoric acid, or ammonium phosphates (MAP and DAP). Potash is usually added in the form of potassium chloride. Heat can be supplied as steam or as steam combined with chemically generated heat. The compatibility of the materials used in the final mix is very important for good storage characteristics.

The process configuration also depends on the raw materials, especially if phosphoric acid and ammonia are used. IFDC is studying process alternatives, such as a preneutralizer or pipe and pipe-cross reactor, in which ammonium phosphates are made. This work emphasizes the conditions for drying, screening, minimizing recycle and dust formation, and improving product quality. A product grade of 17-17-17 (N-P_2O_5-K_2O) is typical of that being studied.

During 1984 IFDC continued to evaluate the compaction type of granulation using only dry raw materials. Using materials that are compatible, such as urea (dust, prills, crystals), ammonium phosphates, and potassium chloride, IFDC's fertilizer technologists found compaction to be a simple way of making complex NPK fertilizer. It is also a very convenient way of adding solid micronutrients. Particles of compacted granules are shaped differently from granules made in a rotary drum or pan granulator. IFDC is investigating the effect of particle characteristics on storage quality.

Physical Quality Studies

IFDC is aware of the importance of physical quality of fertilizer products, especially when the fertilizers are to be used in high-humidity and high-temperature conditions. Essentially all experimental products are evaluated for one or more physical properties. As expected a number of factors affect the physical quality.

During 1984 IFDC began a program to compare the physical quality of NPK fertilizer made by conventional granulation versus bulk blending. Components in granulated mixtures and bulk blends have different degrees of surface contact. The components in a granulated mixture have a much larger surface contact area compared with components in a bulk blend where contact only occurs between the relatively large granules. Three grades (N-P_2O_5-K_2O) of fertilizers (28-28-0, 19-19-19, and 17-17-17) were compared, each grade contained urea as the major nitrogen source. The 28-28-0 and 17-17-17 grades were tested with and without two types of conditioners. One conditioner consisted of 0.5% SAE 20 motor oil and 2.0% kaolin clay; the other conditioner was 0.5% amine and 2.0% kaolin clay.

The fertilizer analysts subjected the products to three standard tests, including critical relative humidity, moisture absorption-penetration, and small-bag caking tests during storage. Bulk blends were less hygroscopic (higher critical relative humidity) than cogranulated mixtures. Penetration of moisture into the bulk blends was much deeper than that into the granulated mixtures. Strength of the moist granules of the bulk blends was much higher than that of the granulated mixtures. A conditioner was needed to prevent or minimize caking of the granulated mixtures; whereas, the bulk blends did not require conditioning. These results indicate the importance of determining physical properties and matching the quality to the product handling system.

Socioeconomics Research

In order to develop improved fertilizer technologies and have them adopted in developing countries, it is necessary to determine what benefits the farmers and the country will receive from using the technologies. An efficient search for appropriate technologies, therefore, necessitates analyses of socioeconomic conditions under which the farmers operate. Such analyses are needed during all stages of the research, development, and technology transfer process.

IFDC's socioeconomics research, therefore, gathers the information needed for an analysis upon which to base various research and development policies. IFDC's economics and sociological research has developed into three major work areas.

Fertilizer Evaluation Program and Information System

During 1984 IFDC established a Fertilizer Evaluation Program and Information System (FEPIS) to promote the use of proper methodologies for fertilizer experimentation, to provide agroeconomic evaluation of fertilizer products and practices, and to facilitate the exchange of data on fertilizer research results between IFDC and other international agencies and national organizations.

This program provides guidelines and technical assistance for systematic agronomic and economic evaluation of fertilizer products and fertilizer management practices in the diverse agroclimatic environments of the tropics and subtropics. The system will generate information and make it available to researchers and decision makers throughout the national and international organizations involved in agricultural research and development. This program will also provide advisory services and training on data analysis, fertilizer evaluation methodologies, statistical and economic analysis, crop modeling techniques, and fertilizer-related research planning.

To achieve these objectives, the program was established with three main components (Figure 15):

1. A fertilizer database system.
2. Data analysis and modeling services.
3. Fertilizer efficiency information system.

FEPIS staff members include an agricultural economist, a crop modeler, and a biometrician, supported by computer programmers and data processing specialists.

In 1984 FEPIS activities were mainly related to the procurement of proper computer hardware and software and the establishment of basic guidelines for data management and advisory services. Numerical routines for statistical analysis were tested and installed, and a database management system was selected for fertilizer information management. Specification of a minimum data set for field experimentation and crop simulation was initiated to standardize data collection, data transfer, and data evaluation. Statistical and economic analysis and data processing services were provided for field experimentation studies in nitrogen efficiency and phosphorus

management for the following African countries: Togo, Sierra Leone, Burkina Faso (formerly Upper Volta), Nigeria, Niger, Mali, Senegal, Kenya, Gambia, Cameroon, and Liberia. Also, statistical and economic analyses were conducted using results of field experiments and research on the use of indigenous phosphate rock resources in Colombia. Advice on data analysis and experimental design was provided for experimentation on nitrogen efficiency studies in the Philippines. Technical assistance in training of field technicians and in planning and executing field trials was provided to the Government of Ecuador.

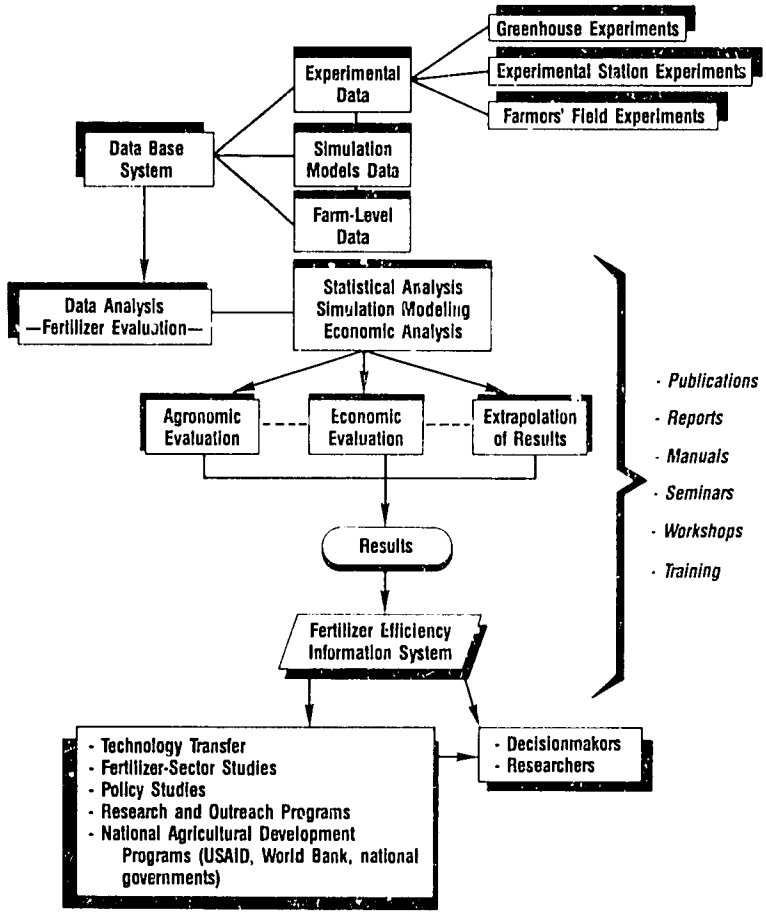


Figure 15. Fertilizer Evaluation Program and Information System.

Simulation Modeling

Simulation modeling techniques were used to study the dynamics of nitrogen efficiency in upland crops. Simulation modeling provides a powerful method of extrapolation of research findings from one area to another area. Construction of a model can also highlight areas of deficiency in knowledge concerning key processes that determine fertilizer efficiency and yield and can thus assist in research planning.

Computer simulation models of nutrient dynamics and crop growth must be able to adequately account for the nuances of climate. These models can further our understanding of fertilizer and crop behavior in diverse environments by quantifying most of this variability.

By providing the capability of rapidly examining a great many fertilizer strategies under various climatic and soil regimes, simulation can play an important role in helping to determine optimum fertilizer strategies.

The CERES-WHEAT-N and CERES-MAIZE-N simulation models describe the processes of crop growth, phenology, water and nitrogen balance, and yield. They have been validated against experimental data in a wide range of environments extending from 58° north latitude to 40° south latitude. A comparison of the wheat model against experiments conducted with various fertilizer treatments, cultivars, irrigated or not irrigated, differing soil types, and vastly different climates shows that the model reliably predicts the yield. The data were developed from experiments in the United States, Canada, Syria, Australia, the Philippines, and the Netherlands.

Where long-term weather records exist, the models can be run to simulate fertilizer experiments conducted over many years. Alternatively, a "weather generator" can be coupled to the model to simulate a sequence of weather and the corresponding crop growth and nutrient dynamics patterns. The variability in yield response to fertilizer and the corresponding nitrogen losses can be described by using statistical procedures known as risk analysis. This procedure enables the researcher to define how frequently various loss processes are operative and what the probability of gaining a response to fertilizer is. This analysis could be extended to quantify and evaluate the economic benefits, costs, and risks associated with the use of nitrogen fertilizers.

Fertilizer Adoption

Social science field research of the IFDC/CIAT Phosphorus Project in Colombia investigates the probability that farmers in the area will accept the fertilizers and fertilizer practices proposed as alternatives to their current technology. For example, the direct application of finely ground phosphate

rock requires changes in the farmers' soil management practices and fertilizer handling and application methods. For those farmers accustomed to using NPK compound fertilizers, the use of a single-nutrient fertilizer requires substantial changes in the methods of application.

The evaluation of acceptability of alternative phosphorus fertilizers can be divided into five major objectives and lines of investigation. First, the farmers' current fertilizer use technology is determined and low-cost methods are developed for gathering information to be used as an input in the design of on-farm trials. Second, cost of production studies are made for crops grown under farmers' currently used technology in order to provide a basis for comparison between the old and new (experimental) technologies. Third, the potential target groups and beneficiaries who may profit from the development of new phosphorus fertilizer products are determined. Fourth, methods for farmer participation in on-farm testing are developed. Fifth, a survey is made of the early adoption trends.

The relative cost of fertilizer as compared with the farmers' total cost for producing a crop determines the likelihood that they will find that fertilizer attractive. For example, if phosphate rock is agronomically effective farmers in locations such as Nariño, Colombia, might find the changes in practices required to use this fertilizer economically attractive in the potato crop where fertilizer costs represent 28% of their total expenditure. However, in maize/bean associations the potential benefit to the individual farmer will not be so great because fertilizer costs only represent 7% of their cash expenditure.

Early Trends in the Acceptance of Phosphate Rock by Colombian Farmers

In two of the IFDC/CIAT Phosphorus Project's pilot-testing zones—Cauca and Nariño—finely ground phosphate rock became commercially available on a scale that made it possible to investigate some early trends in farmer acceptance of this product. This survey showed that much information is yet needed for farmers to use phosphate rock technology effectively and that knowledge of fertilizer is a potentially limiting factor to successful diffusion of directly applied phosphate rock in small farm systems where technical assistance is thinly spread.

Most farmers who have tried finely ground phosphate rock in each area reported favorable results. Most of this farmer experimentation was conducted without significant technical assistance. Two factors, in particular, need to be addressed to ensure that this favorable climate for acceptance persists. First, farmers in Narino were applying phosphate rock to almost every crop and cropping combination including pastures. Systematic information on which crops are suitable for this technology is still lacking. Second, there is considerable confusion among farmers about the proper time and method for application of finely ground phosphate rock. Future research and testing are needed to clarify which crops, methods, and timing of application are appropriate in order to obtain widespread farmer acceptance of phosphate rock technology.

Market Situation and Outlook

Farm-Level Fertilizer and Crop Prices

During 1984 IFDC continued to collect and analyze monthly farm-level

A Colombian farmer discusses his fertilizer practices with IFDC social scientists, Dr. Jacqueline A. Ashby (second from left) and Dr. Scott Guggenheim (extreme right), who are conducting a rapid diagnostic survey.

prices for principal fertilizer products and crops for 41 countries in Africa, Asia, and Latin America. Data collection from in-country sources began in late 1979 and has been continued on a monthly basis. Prices are in local currency and are converted to a standard unit (US $/mt). This information is maintained on a computer 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, are of value to policymakers in developing countries. This information is also useful in analyzing various policy proposals to determine why farmers in some countries apply fertilizer at a much higher rate than in other countries.

Fertilizer Price Survey

IFDC in July 1984 conducted a fertilizer price expectation survey to determine the changes in international fertilizer prices that are expected by marketing managers, import managers, and market research managers for the following 6 months. This information was used in IFDC training programs and provided as a service to the fertilizer industry. Respondents were asked to estimate the percentage of changes in fertilizer prices expected between July 1, 1984, and January 1, 1985, in the world market prices of urea, ammonium sulfate, DAP, TSP, and muriate of potash (MOP).

Forty-one organizations around the world participated in this study. Geographical balance among the respondents was very good.

Regional Supply/Demand Statistics

IFDC continues to have a large number of requests for fertilizer product statistics. Our economists have tried to compile as much data as possible on product types since a considerable amount of data is available on a nutrient basis. Data on a product basis is obtained directly from correspondents in developing countries. At the present time IFDC has product information on approximately 76 developing countries. The countries supplying statistics use about 94% of the fertilizer consumed in developing countries. Three regional reports, which included product data; information on regional trends on fertilizer production, consumption, imports, and exports by nutrient; and published data on fertilizer production capacity, were prepared during 1984. These reports include the "Africa Fertilizer Situation," Asia Fertilizer Situation," and "Latin America Fertilizer Situation." In addition, developing countries are also interested in conditions in the developed countries. We have published a report on the "Fertilizer Situation in the Developed Countries." All four of these reports will be updated approximately every 6 months with the latest product information available.

Subsidy Report

IFDC frequently obtains requests for current information on fertilizer subsidies from various countries. Recently fertilizer subsidies have received much attention from government policymakers. As fertilizer consumption has increased, the cost to maintain subsidies has likewise increased. Many countries are now closely examining their subsidy policy. The importance of fertilizer subsidies is illustrated by the fact that a large number of countries have dropped their present fertilizer subsidy, have reduced it, or have adopted a new subsidy policy. IFDC felt that it would be very helpful to policymakers to examine the different experiences that countries have had with subsidies. Short papers describing the current status of subsidies of mid-1984 were prepared for 17 developing countries including Argentina, Burkina Faso, Chile, Colombia, Gambia, India, Indonesia, Ivory Coast, Nepal, Philippines, Saudi Arabia, Sierre Leone, Sri Lanka, Turkey, Venezuela, Zambia, and Zimbabwe. This report examines the experiences that these countries have had with fertilizer subsidies. Each report was written by an author who is an authority on fertilizer in his country. Twenty-five authors from developing countries participated in this project.

Photo on opposite page:
This Malian farmer is an active participant in IFDC's Malian phosphate project.

National Programs

Since its inception 10 years ago, IFDC has strived to make its fertilizer technology applicable to the conditions of the countries of the tropics and subtropics. One means that it uses to achieve this end is the development of national programs. Through national programs, IFDC can evaluate in developing countries its fertilizer technology, which is developed at Headquarters.

At present IFDC has established programs in Bangladesh, Indonesia, and Mali. The longest running program, that of Bangladesh, continued to help provide Bangladeshi farmers with increased quantities of fertilizers to raise crop production levels. In Indonesia that program continued to search for ways to improve nitrogen efficiency in flooded rice, to identify effective fertilizer management systems for upland crops, and to evaluate the economic and social consequences of this research. The 4-year-old program in Mali continued work toward its objective of finding the best possible agricultural use for Mali's phosphate deposit, located in the Tilemsi Valley. Farm-level trials were expanded still further during 1984.

Bangladesh

During 1984 IFDC's fertilizer marketing and distribution consultancy services agreement with the Bangladesh Agricultural Development Corporation (BADC), which began in 1979, received continued support from USAID. A central aim of this project is to provide farmers with increased quantities of fertilizer, which is needed to raise crop production levels to better feed an impoverished and rapidly growing population. The need for fertilizer to increase food output is recognized as a key element of the government's food self-sufficiency agricultural development policy.

Three IFDC resident consultants, who work closely with BADC counterparts, conduct the technical assistance program in Bangladesh. They assist BADC in resolving problems arising in day-to-day management and operation of the New Marketing System (NMS) and in developing, instituting, and monitoring programs to strengthen and improve the overall fertilizer delivery system. The participatory nature of the resident consultant assistance program provides a practical approach to problem solving and fortifies and expands skills of BADC marketing staff.

In 1984 the resident consultant programs assisted BADC in upgrading the operations and cost efficiency of the new marketing system. Additional program support was supplied by short-term consultants from the IFDC Headquarters' staff who studied specific problem areas that required specialized expertise. As in the past, training was an important component of the IFDC assistance package. Personnel from BADC and other Bangladeshi fertilizer-sector organizations took part in IFDC-sponsored and other training programs and study tours.

During the 1983/84 fertilizer year, the NMS handled record sales of 1,128 million tons. In view of the successful changeover to the private-sector dealer oriented NMS, consideration is being given to developing a large-scale wholesaler network under the second phase of USAID's fertilizer distribution improvement project.

These Bangladeshi women are winnowing wheat.

Fertilizer Distribution

Improvements in the management and operation of the physical distribution system were continued under the direction of the IFDC resident distribution consultant. In 1984 efforts were made to improve the operation of the previously introduced fertilizer stock control and accounting procedures, the warehouse management, and the movement planning and routing systems.

Refresher training programs were conducted for all 22 district office staff personnel engaged in preparing stock control and accounting reports used to monitor fertilizer availability on a countrywide basis. The distribution consultant prepared a comprehensive report consolidating 1983/84 sales by BADC sales point, by district, by division, and by product. A report detailing 1983/84 fertilizer product movement by mode of transport and route was completed and distributed.

The distribution consultant assisted BADC in revising the provision of its fertilizer transport and handling contract before the 1984/85 and 1985/86 contracts were submitted for bids. A least-cost fertilizer movement plan guide for 1984/85 was prepared. This report shows least-cost routing by mode of transport from a product's origin to its primary distribution point (PDP). Quarterly movement plans for 1984/85 were prepared on the basis of PDP product sales targets, product sources, and least-cost routing. A projection of total movement and handling costs for 1984/85 was prepared from this information. A review of 1983/84 incidental (marketing) costs indicated that movement and handling costs conformed closely to least-cost routing estimates.

Assistance was also provided in procurement planning. A study of urea buffer stock requirements was made to facilitate planning of procurement from local factories. A review was made of 1984/85 fertilizer import requirements, by month and by port of receipt.

Fertilizer Marketing

In 1984 IFDC's marketing consultant continued to help BADC personnel increase the efficiency of the marketing system. Performance of the 1983/84 marketing plan was monitored. Sales targets were established by PDP and by product, and advice was given on supply procurement and movement strategies to overcome spot shortages in supply that arose late in 1984.

The monthly survey that monitors fertilizer availability; prices paid by farmers; source, usage, and cost of credit; fertilizer use rates; sources of information about fertilizer use; and the prices farmers received for their crops was expanded to cover 20 districts and approximately 1,000 farmers. With the assistance of an IFDC Headquarters' economist, the marketing resident consultant revised the farmer questionnaire to facilitate data tabulation and analysis by computer. Computerization of the survey data began in November 1984.

Monitoring of the BADC fertilizer wholesaler credit program, in which the loans were secured by bank guarantees, indicated that the program was operating effectively with no defaults recorded. It was recommended that credit fund availability be increased and greater dealer participation encouraged.

Dealer Development and Training

Dealer training continued to receive high priority because of the important role of dealers in influencing and promoting increased and more efficient use of fertilizers by farmers.

BADC district dealer training officers took part in "train-the-trainer" programs designed to expand and strengthen their knowledge on the subjects of fertilizer marketing. This information was in turn passed on to fertilizer dealers at district-level meetings conducted by BADC trainers and often attended by BADC management and senior-level marketing personnel. Response to dealer training meetings remains highly favorable.

The IFDC resident consultant assisted BADC in reviewing planned revisions in dealer-oriented sales promotion and technical assistance training aids including preparation of soils maps and fertilizer recommendations based on the best information available from the Bangladesh Agricultural Research Council (BARC) and other government research organizations. Work was continued on updating the curricula for both train-the-trainer and dealer training meetings.

Special Projects

Agronomic Services

A Coordinated Fertilizer Efficiency Research Project was carried out by IFDC in association with BARC and its affiliated organizations.

The objectives of the project are to:

1. Determine the efficiency of deep placement of urea in the soil relative to split applications of broadcast urea for rice production.
2. Test and modify prototype applicators for fertilizer placement in paddy.
3. Provide training for specialists in fertilizer efficiency research.

In 1984 nitrogen management experiments were continued and phosphate source tests initiated on rice grown in successive seasons on a series of principal types of soil. In the nitrogen test program, conducted at an experiment station, basal applications of deep point-placed urea generally outperformed conventional split broadcast applications of urea in terms of yield response and agronomic efficiency (kilograms of paddy produced per kilogram of nitrogen). Results of experiments during 1983 Aus and Boro seasons indicated that in several locations yield responses to urea may be increased by 25% to 50% through deep placement of urea. Net returns from deep-placed urea were higher than those from split broadcast urea in most experiments after the additional labor costs for the former method were taken into account. An analysis was made of the status of the micronutrient zinc, its use, supply, and short-term future demand in Bangladesh. Increased use of zinc is foreseen as zinc deficiencies in rice and other crops become more pronounced with more intensified crop production.

Prototype applicators for placing urea into soil were obtained from IRRI and Fujian Academy of Agricultural Sciences, China. Evaluation of the performance of the applicators in approximately 150-m² plots revealed that all of the continuous-feed applicators had a field capacity of 0.13-0.18 ha/hour and were relatively easy to operate. The cup-feed applicators provided the best metering accuracy. However, the spring-auger and deep-plunger applicators resulted in best placement and coverage of the urea (lowest percentage of applied N in the floodwater at 24 hours after application). The variability in quantity of nitrogen entering the floodwater when urea was hand deep-placed shows the importance of proper placement and coverage of the urea when this method is used. The lack of precision in hand placing the urea during the various experiments may be one variable that has caused differences in relative efficiencies among the methods of application.

Surveys were conducted at three cropping systems research sites to determine farmers' fertilization practices. The data were used in the design of on-farm N management trials. A high percentage of farmers use manure, and all use fertilizer. Most farmers generally use more nitrogen and phosphate than potash.

Fertilizer Pricing Policy

In 1984 IFDC completed a study of the economic impact of fertilizer price

deregulation on farm-level fertilizer prices. The time series data used in this analysis were generated from the farmer fertilizer surveys carried out by the IFDC marketing consultant. The study dealt with actual retail prices paid by farmers for urea, TSP, and muriate of potash. It compared the economic implications in three distinct phases of fertilizer price policy: (1) price regulation throughout the country, (2) segmented market with price deregulation in one part of the country (effective April 1, 1982) and price regulation in the other, and (3) price deregulation in the country (effective April 1, 1983).

Selected conclusions of the study are as follows: first, price levels and variability were higher in deregulated market areas than regulated market areas. However, these differences could not be attributed to the initiation of price deregulation policy. Both price differences and variability declined as Bangladesh converted its fertilizer policies from complete price regulation to complete price deregulation.

Second, the actual fertilizer prices paid by farmers were generally not the same as those established by the government. Even though government prices did serve as a reference for market prices, the policy was not really effective. Under deregulation, all the resources needed to enforce the government's price policy can be saved and invested in alternative projects having greater economic returns.

Third, the actual fertilizer subsidy was higher than the estimates indicate. Government intervention through fertilizer subsidy tends to lead to misallocation of resources and hence reduction in resource use efficiency. However, any effort to lower fertilizer subsidy must be accompanied by elimination of controls on crop prices and an improvement in fertilizer productivity.

Fourth, the economic impact of fertilizer price deregulation on retail fertilizer prices would be favorable only under an efficient fertilizer marketing system, stable fertilizer supply situation, and competition among fertilizer dealers. Price regulation would not solve the basic problem of inefficiencies in the system.

The results of this study and its implications for fertilizer pricing policy in Bangladesh and other developing countries were presented in the report entitled "Fertilizer Price Deregulation and Public Policy—The Case of Bangladesh."

Personnel Training

IFDC continued to provide training to personnel from BADC and other government organizations. Personnel participated in IFDC-sponsored training programs at Headquarters and in Bangladesh.

The IFDC dealer development and training resident consultant, in cooperation with an International Agricultural Development Service (IADS) resident consultant and BARC staff members, developed and conducted a Fertilizer Efficiency Research Refresher Course in Bangladesh. This was a followup to a similar course held in 1983. The program was funded by a USAID program administered by IADS. Thirty-two participants from nine Bangladesh agricultural research and extension organizations took part in the 3-week program whose main objective was to strengthen the participants' skills in collecting, organizing, and analyzing the results of fertilizer efficiency trials at the experiment station and farm level.

IFDC resident consultants assisted BADC in organizing and conducting a 2-week, in-country fertilizer marketing management program for 31 members of BADC marketing staff. On the basis of the positive response from BADC management and staff, similar in-country programs are planned for the future.

Representatives of BADC and the Ministry of Agriculture of Bangladesh participated in IFDC's training programs on (1) Use of Microcomputers for Fertilizer Sector Personnel, (2) Statistics and Economics of Fertilizer Use, and (3) Fertilizer Distribution and Handling Training Program.

Participants establish an experiment during IFDC's Fertilizer Efficiency Research Refresher Course in Bangladesh.

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 is funded primarily by the Australian Development Assistance Bureau. Three IFDC resident consultants are located at the Centre for Soils Research (CSR). Through CSR they advise and assist three working groups (Lowland, Upland, and Socioeconomic) of the National Fertilizer Efficiency Program on activities related to the objectives of the Program. The working groups are searching for ways to improve nitrogen efficiency in flooded rice, to identify fertilizer management systems that will prove effective on upland crops, and to evaluate the economic and social consequences of this research.

Rice is a major food crop produced and consumed in Indonesia. Eighty percent of the nitrogen used in Indonesia is applied to rice. Since the efficiency of fertilizer nitrogen applied to rice is known to be low, a major portion of the 1984 program activities was dedicated to identifying the causes of low nitrogen efficiency in Indonesian rice production and evaluating technologies that will afford an economic solution to the problem. Most of these activities have been centered in the Socioeconomic and Lowland Working Groups.

Indonesian workers transplant rice at a Centre for Soil Research pilot area.

Socioeconomic Working Group

Previous research in Indonesia and research done by the International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) has shown that deep placement of nitrogen is an effective means of improving nitrogen recovery by the rice plant and increasing yields.

A primary activity of the Socioeconomic Working Group during 1984 was to conduct a technical and economic evaluation of urea deep-placement technology as it applied to Indonesia and to establish pilot areas that will allow further evaluation of this technology. There were three components of this evaluation: (1) technical and economic assessment of producing and marketing USG, (2) technical and economic evaluation of hand- versus machine-placed USG, and (3) evaluation of the effectiveness of USG technology in farmers' fields.

Economic Assessment of Producing and Marketing USG

The objective of this assessment was to develop a reasonably accurate estimate of the expected farm-gate cost of USG in Indonesia. It should be noted that there had been no commercial production of USG by any process and, therefore, it was necessary to make a number of assumptions where concrete data were lacking. As a result, a substantial margin of uncertainty exists in the projected costs and technical suitability of the alternative processes considered. The cost of producing USG on a commercial scale was compared with the cost of producing this material in research and development-scale production units. These costs were then compared with the cost of producing prills in a newly built commercial-scale plant. The key conclusions are:

1. The plant-gate cost of USG in a commercial-scale plant would be about 5% more per ton than that of prilled urea—US $148/ton for USG as compared with US $141/ton for prilled urea.
2. Over the short term, the costs of marketing USG are expected to be 30%-35% more than those of prills, but over the long run there should be no difference. This is because of the relatively low throughput and specialized handling requirements of USG. Based on the assumption that a USG production site is in Sumatra and the market in Java, the marketing costs of USG are expected to be about US $58-$63/ton depending on the method of transport used. This

compares with a marketing cost of about US $44/ton for urea prills.

3. The farm-gate price of USG will be 5%-12% higher than unsubsidized prilled urea because of increased marketing costs of USG.
4. Small-scale USG production units may be feasible in special situations. Initially the market is not likely to be large enough to justify a national-scale (1,750 tons/day) USG plant. Smaller production units are needed to develop the market and/or carry out the needed research and development to solve some of the technical problems associated with producing USG. The working group looked at the options and compared two other possibilities for producing USG. One was to retrofit an existing urea plant to produce USG at the rate of 250 tons/day. The other option was to build a special briquetting unit (500 tons/day) in the center of the market. This comparison revealed that the farm-gate cost of USG would be about 24%-27% more than that of unsubsidized prilled urea being produced and marketed from urea production units currently operating at these locations. However, the USG costs were below those for prilled urea produced in newly built, large-scale commercial plants.

Technical Evaluation of Hand Deep Placement Versus Mechanical Deep Placement of Urea

While deep placement of urea is known to result in greater nitrogen recovery by the rice plant and higher yields than broadcast prilled urea, hand placement seems to be the only practical means of accomplishing this at this stage in the small rice fields of Indonesia. Two institutions, IRRI and the Fujian Academy of Agricultural Sciences (FAAS), have done research on applicators and have released several for field testing. Tests were made at Sukamandi Research Institute for Food Crops and at Muara, near Bogor, to compare methods of deep placement under two levels of land preparation (one pass with a rotary cultivator versus three passes). Five methods of fertilizer application were compared:

1. Broadcast application of prilled urea.
2. Deep placement of USG by hand.
3. Deep placement of USG with Chinese cup feeder applicator.
4. Deep placement of USG with IRRI press wedge applicator.
5. Deep placement of prilled urea with IRRI spring auger applicator.

Results of these trials can be summarized as follows:

1. None of the machines tested appear to be ready for distribution to the farmers.
   a. Land preparation greatly affects the performance of mechanical applicators. All mechanical applicators performed better when the land was well tilled (three passes with a rotary cultivator).
   b. The metering of fertilizer varies markedly among machines depending partly on water and soil conditions. The spring auger was the least accurate of the machines tested, dispensing 8% less fertilizer than the calibrated value when land preparation was poor to 19% more when the land preparation was good. The press wedge had the most accurate metering of the applicators tested varying less than 2% from the desired rate.
   c. All applicators allowed too much urea nitrogen to enter the floodwater.
2. The labor required to apply fertilizer varied markedly with the method of application. The number of hours required per hectare to apply 58 kg of nitrogen using the various methods were as follows:

An Indonesian worker uses a mechanical applicator to deep place urea supergranules.

Surface broadcast	5.0 hours
Deep placement by hand (USG)	80.0 hours
Deep placement by machine	
Chinese cup feed (USG)	13.4 hours
Press wedge (USG)	9.9 hours
Spring auger (prilled urea)	9.4 hours

3. Hand deep placement by unskilled workers resulted in unusually high concentrations of nitrogen in the floodwater. These concentrations were reduced markedly when work was done by researchers or by farm laborers instructed in the importance of proper placement and coverage.

Economic Analysis of Deep Placement of Urea—Farm Level Evaluation

Detailed economic studies were made to compare (1) broadcast application of urea with hand deep placement of USG and (2) alternative methods of deep placement (hand versus machine). Results of these studies are summarized as follows:

1. The economics of hand deep-placed USG is strongly affected by price. The economic superiority of USG was greatest when urea was not subsidized (prices higher). Under present subsidized prices in Indonesia (urea farm-gate price of US $82/ton), USG is economically superior where prilled urea is surface broadcast at a rate of 120 kg/ha or less. The estimated economics of deep-placed USG improves where the economic prices of USG and prilled urea are compared (US $185/ton for prilled urea and US $206/ton for USG).
2. The economics of machine deep placement of urea is highly dependent on the operating cost of the machine and the price of the urea. The cost of deep placement of urea by use of a machine has not been established because no suitable applicators have been developed that can duplicate the effectiveness of hand deep-placed urea. However, it is known that the cost of hand placement of urea at a rate of 58 kg/ha is about US $12/ha (at the present wage rate in Indonesia). It is also known that the costs of mechanical and hand application are the same when the operating cost of the applicator is about US $6.20/ha. For applicator-placed USG or briquettes to have a higher net return than hand-placed USG or briquettes, the operating cost of the applicator must be less than US $6.20/ha.

Conclusions drawn thus far indicate that higher yields and greater economic returns are possible with urea deep placement compared with conventional broadcast application of prilled urea. The magnitude of this gain will depend on such factors as crop response to fertilizer and cost, including application and amount of fertilizer used by the farmer.

Farm Surveys

A questionnaire was distributed among the farmers to obtain a profile of the practices followed in two pilot areas. Information gathered included farm size, ownership, use of credit, and farming practices, including levels of fertilizer use, water management, use of labor, etc. Preliminary findings indicate the following:

1. Rice farmers in the Subang area (West Java) may be using more nitrogen than the agronomic optimum. They apply an average of 160 kg N/ha and on rare occasions up to 400 kg N/ha.
2. Farmers in Ngawi (East Java) use considerable quantities of organic manure; more than one-half of those interviewed used organic manures as well as chemical fertilizer nitrogen.
3. Residual levels of nitrogen in the soil may limit nitrogen response in farmers' fields. Experiments conducted in farmers' fields in the Subang survey area showed that the maximum yields were obtained with only 58 kg N/ha. The general recommendation for rice is 90 kg N/ha. The pilot-area nitrogen trials in farmers' fields of West Java showed no response to nitrogen. This may be due to high residual nitrogen or nitrogen additions from neighboring paddy through continuous flow of paddy water.

Lowland Working Group

The resident consultant assigned to work with the Lowland Working Group spent most of his time identifying the magnitude of fertilizer nitrogen losses in rice, determining some of the causes of these losses, and suggesting strategies that might effectively curb these losses. Some of his key findings and implications of this research were:

1. Usage of nitrogen beyond the agronomic optimum increases the empty rice spikelets. In all experiments conducted, an excess of urea did not decrease the recovery of fertilizer nitrogen by the plant. However, the proportionately higher concentration of nitrogen in the plant with an increased application rate induced a higher percentage of empty spikelets.
2. Ammonia volatilization losses from broadcast urea can be high, but vary with soil type and floodwater depth. Under the conditions at Sukamandi Research Institute for Food Crops, the amrnonia volatilization losses can be high (up to 60% of nitrogen applied) in floodwater when urea is broadcast.

With soils near Bogor and in the Subang district (both in West Java), much lower ammoniacal nitrogen concentrations in the floodwater were observed for the same amounts of urea applied and ammonia losses were, therefore, lower. This may be due to their higher cation-exchange capacities compared with those soils of the Sukamandi area.

3. When prilled urea is broadcast, most of it should be applied between 3 and 5 weeks after transplanting because very little nitrogen is taken up by the plant before that time.
4. Urease inhibitors or controlled-release coatings may not be effective in increasing nitrogen efficiency of urea where continuous flow of irrigation water prevails.
5. Deep placement of urea is likely to be more effective under farmers' water management than experimental results indicate because in the experimental plots floodwater is kept stationary and its depth maintained by water additions. This minimizes the runoff losses of prilled urea that naturally occur in the farmers' fields where there is continuous flow of irrigation water. Thus, the experimental results indicate an unrealistic yield for broadcast urea over deep-placed urea, which encounters practically no runoff loss in either case.
6. The nitrogen fertilizer efficiency of deep-placed urea is comparatively higher when the application rates are low.
7. Deep placement of urea by farmers could result in a substantial saving of irrigation water on Java. In West and Central Java many farmers drain their fields just before they broadcast urea. After fertilizer application, the fields are left in this drained condition for 3 to 5 days, and then the field is reirrigated. Deep placement of urea may eliminate the need for this practice.

Upland Working Group

Activities of the Upland Working Group were focused in the Outer Islands. Attention was directed toward evaluation of PAPR, phosphorus, and lime rate studies, and phosphorus interactions with other nutrients in the soil. The number of experimental sites was increased to 11; locations in West Java, Sumatra, Kalimantan, and Sulawesi are now included.

Use of Tilemsi Phosphate Rock

Since 1981 IFDC, with the support of the International Development Research Centre (IDRC) and the World Bank, has been assisting Malian research and development organizations in finding the best possible agricultural use for Mali's 20-million-ton deposit of high-quality phosphate rock located in the Tilemsi Valley, north of Gao. The objective of this work is to identify the best way of using the Tilemsi rock so that reliance on expensive imported phosphate fertilizers can be reduced or even eliminated. Therefore, sophisticated research station trials comparing ground Tilemsi rock, PAPR at 15% or 30% acidulation from Tilemsi rock, and imported TSP were established in 1982. The trials were complex as comparative information was needed not only on various forms of phosphate but also on the influence of rates and methodology of application; the expected importance of residual effects was considered.

The effects of the major climatic factors and crops of Mali on physical crop response to phosphate were also studied. This information was needed to develop a model for the phosphate fertilization of Malian crops that could be used as a guide for the government and the farmers on the most suitable use of phosphate in agricultural production.

Based on the early results from these research trials, simplified farm-level trials on cotton and maize were established under the sponsorship of the World Bank-funded Mali-Sud Project of the Compagnie Malienne Pour le Developpement des Textiles (CMDT).

All fieldwork was carried out by the Division de la Recherche Agronomique (DRA) of the Institut d'Economie Rurale (IER) with IFDC providing the necessary support. The work with the CMDT, of necessity, involved the field staff of CMDT who cooperated closely with DRA/IER and IFDC in the conduct of the farm trials.

The program as it now stands combines, therefore, the research and development activities needed as a base for future farm-level action programs.

On-Station Experiments

On all of the research stations, the phosphate level of the soil was very low, and good response could be anticipated. Experimental trials were conducted at 10 selected research station sites representing the major soils, climatic patterns, and cropping sequences in Mali. Four types of experiments were designed as follows:

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

The general response model developed shows the outstanding performance of Tilemsi phosphate rock when used both annually and as basal applications on maize, cotton, and rice. In the regression model with the experiments on maize the most critical factors affecting the crops' response to both annual and basal applications of phosphate rock were the pH of the soil and the rainfall during a period that extended from 10 days before to 20 days after planting. In the regression model with groundnuts the most critical factors were the pH of the soil and the rainfall between 10 days before and 50 days after planting. In the model for the sorghum and cotton experiments, the shorter rainfall periods of 10 days

before to 20 days after planting and the longer rainfall period from 10 days before to 50 days after planting were both significant. As rainfall becomes more favorable, i.e., with generally better crop establishment, the response to direct application of phosphate rock improves.

In experiments where annual phosphates followed basal phosphate rock application, annual requirements for phosphate applications were reduced markedly. The largest residual effect of basal application occurred in the second year. This residual effect could, depending on local conditions (mainly climatic), be so important that no response to additional phosphate application was observed on second year's maize or third year's cotton. On sorghum, phosphate rock application can be recommended as quite good response was observed. In the millet-growing area, although TSP shows the highest net return, phosphate rock can be recommended for this low-input and low-income crop. Groundnut response to phosphate fertilizer was very limited in all zones.

Based on these series of experiments, the work in Mali has been able to show that, provided the necessary complementary fertilizer nutrients are applied, Malian farmers can effectively use Tilemsi phosphate rock as the phosphorus component in their fertilization practice. On very low phosphorus status soils, supplementary applications of soluble phosphate may initially be required to achieve maximum profits.

Experiments on irrigated rice in the Office du Niger show that phosphate rock can be effectively used for that crop also.

Farm-Level Trials

The number of farm-level trials on maize and cotton in the CMDT zone was increased from 60 in 1983 to 96 in 1984 and included all of the regions in the CMDT intervention area. 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, the recommended practice using soluble complex fertilizer, and two application rates of phosphate rock (60 and 120 kg P_2O_5/ha) was used at each of the 96 farms.

Results show that in the CMDT zone, phosphate rock, supplemented by the necessary N, K, and S at the same level as in the cotton mix, can sustain yield levels similar to those obtained by the recommended fertilization. In addition, this work has shown that crop response to phosphate fertilizer under farm conditions is much lower than anticipated and that the rates currently recommended for phosphate rock in the CMDT zone are much too high—they could probably be reduced by half. The on-station trials indicated that phosphate rock could replace soluble phosphates as of the second year after application, and this fact has been confirmed in farmers' field trials.

Interviews with farmers have indicated that they were very enthusiastic about phosphate rock because it is effective and relatively cheap (US \$0.236/kg P_2O_5 compared with US \$0.606/kg P_2O_5 for the cotton mix; moreover, they appear to be proud that a Malian product could replace a major element in the expensive imported cotton mix fertilizer. The dustiness of the phosphate rock, seen by the extension service as a major obstacle to its use, has only limited negative impact on their enthusiasm once they understand the economics of phosphate rock use.

Technical Assistance

Technical assistance is one of the ways that IFDC's research and development accomplishments are transferred to fertilizer sector personnel in developing countries. IFDC research personnel and technicians keep abreast of all technologies that have potential for helping developing countries improve their food production.

During 1984 most of IFDC's technical assistance activity was centered in Africa, with projects in Burkina Faso, Cameroon, Egypt, the Ivory Coast, Niger, and Nigeria. Other activities involved Malaysia, the People's Republic of China, and the Philippines in Asia; in Latin America, activities were focused on Brazil, Ecuador, Mexico, and Venezuela.

Various types of work are involved in the technical assistance component. For example, it may include helping improve the production capability of a specific fertilizer plant, increasing the effectiveness of a marketing system, assisting in making a decision relative to pricing policy, or providing guidance on future investments in fertilizer production or marketing.

Since technical assistance represents a practical application of fertilizer technology, its results are easily measurable in terms of production increases and cost reductions. Fertilizer plant modifications to improve operation, update existing facilities, or include new technology are not initiated unless results of increased efficiency, increased production, or lower costs are expected. Examples of the benefits experienced by various recipients of IFDC's technical assistance are given in the booklet, *The IFDC Story*, IFDC—G-5, which is available free of charge.

Improvement of Research Capability at Egyptian National Research Centre

Through funding from the U.S. National Academy of Sciences, IFDC previously supplied a bench-scale wet-process phosphoric acid unit to the Egyptian National Research Centre. During 1984 an IFDC engineer spent 4 weeks in Egypt to assist in initial start-up and operation of the unit using selected Egyptian ores. The unit produces filter-grade (28%-30% P_2O_5) phosphoric acid, which is batch concentrated to merchant grade (54% P_2O_5). This facility represents the first of its type to be installed in Egypt.

Studies of Partially Acidulated Rock for Niger

As part of its African fertilizer research program, IFDC is conducting agronomic evaluation of Parc W phosphate rock from Niger for phosphate fertilizer production at IFDC. Parc W phosphate rock has been used to produce PAPR—granular and run-of-pile. It is also a suitable raw material for making SSP. Niger also has another rock deposit at Tahoua, but IFDC has no firsthand experience in processing rock from this source.

USAID sponsored a technical/economic evaluation of using Parc W and Tahoua rocks in Niger to produce PAPR in granular or semigranular forms. Phosphate rock would be acidulated with sulfuric acid. The four schemes that IFDC evaluated were:

1. 100-tpd PAPR using Parc W rock to make a semigranular product.
2. 100-tpd PAPR using Parc W rock to make a granular product.
3. 200-tpd PAPR using Parc W rock to make a semigranular product.
4. 75-tpd PAPR using Tahoua rock to make a semigranular product.

SSP constitutes a major share of phosphate fertilizer used in Niger. The study compared domestically produced PAPR with imported SSP. Demand for phosphate was projected to the year 2000. The study team estimated investment and production costs and internal rates of return. They considered the economic impact on the country that would be caused by installation of a domestic fertilizer plant. On the basis of assumptions used, the estimates indicated that domestic production of PAPR would be economically feasible. Specifically, the unsubsidized retail price of PAPR is almost 15% lower than the unsubsidized retail price of imported SSP. The annual financial saving through PAPR production over SSP imports could be US $0.9 million in the first year and US $1.6 million in the third year of plant operation.

Nigeria Fertilizer Marketing Strategy Development

During 1984 IFDC continued to provide the M. W. Kellogg Company with technical assistance in developing a marketing system to off-take production of the Port Harcourt (Nigeria) fertilizer complex that is under construction. The on-stream 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 has been delayed because other contractual agreements had to be completed. The new estimated date for starting the facility is mid-1987.

The National Fertilizer Company of Nigeria (NAFCON), a company jointly owned by the Nigerian Government and Kellogg, was formed to manage the production and marketing functions of the Port Harcourt fertilizer complex. During late 1983 Kellogg recruited three staff members for NAFCON to assist the Fertilizer Procurement and Distribution Division of the Federal Ministry of Agriculture in procurement, distribution, and financing of fertilizers for 1984 and 1985. In June 1984 NAFCON submitted a plan for ensuring responsibility for the procurement and marketing of fertilizers. IFDC assisted with the plan of action and also gave assistance to the NAFCON team on fertilizer specifications and seeding program activities.

Fertilizer Sector Study for the Ivory Coast

At the request of the World Bank/Ivory Coast, an IFDC team reviewed the fertilizer situation in the Ivory Coast and made recommendations for further studies aimed at improving its fertilizer supply, distribution, marketing, and efficiency of use.

The IFDC mission made proposals for needed in-depth studies to improve the fertilizer supply and marketing systems. The existing fertilizer factory of Siveng, in the port area of Abidjan, has a granulation unit based on the use of imported materials. This is an efficiently run but fairly small-scale operation. A study of Siveng production costs and consideration of bulk blending and importing fertilizers in bulk were suggested as a means to improve supply flexibility and reduce costs.

Recommendations were also made for studies to improve the system for the marketing of fertilizer, including consideration of current government policy, use of private organizations, and effective coordination of agronomic research, fertilizer research, and extension activities.

Feasibility Study for Burkina Faso Fertilizer Plant

In November 1983 IFDC signed a contract with the Government of Burkina Faso (formerly Upper Volta) to conduct a study to determine the feasibility of that country's building a fertilizer plant. In December 1983 project team members visited Burkina Faso and Ivory Coast to collect data and information for use in the feasibility study. Three production schemes were

During a World Bank Mission, Dr. Dennis H. Parish, Director of IFDC's Outreach Division (second from right), discusses cotton production with an Ivory Coast extension agent and farmers.

originally considered in the study: (1) an NPK bulk-blending and bagging plant, (2) a PAPR plant, and (3) a PAPR plant in conjunction with an NPK bulk-blending plant. Plans for the PAPR plants were developed on the basis of partial acidulation of Burkina Faso's Kodjari phosphate rock using sulfuric acid.

The team members assessed the technical and economic viability of the three manufacturing schemes. They evaluated both importation and manufacture of sulfuric acid for PAPR production. The study team estimated capital investment requirements, manufacturing costs, and internal rate of returns on the basis of technical data developed for each scheme. They analyzed the sensitivity of manufacturing cost estimates and internal rate of returns with respect to principal inputs and estimated foreign exchange savings for each scheme.

Results of the study indicated that only part of scheme 3—the bulk-blending and bagging facility scheme—provides a basis for an economically viable project. The principal factors resulting in unfavorable economics for PAPR production were (1) small plant capacities, (2) high transportation cost for phosphate rock, and (3) relative low cost of imported phosphate fertilizer on the basis of currently imported NPK compound fertilizers. The team developed recommendations for the implementation of a bulk-blending and bagging facility.

Cameroon Fertilizer Sector Study

USAID/Cameroon requested the assistance of IFDC in carrying out a preliminary study of the Cameroon fertilizer sector to develop the terms of reference for an in-depth fertilizer study designed to find ways of improving the marketing of fertilizers in Cameroon.

Two IFDC staff members visited Cameroon to gather data and background information on all aspects of fertilizer importing and marketing.

The study team's findings indicated that an efficient fertilizer supply system must be developed if the full potential for increased food production is to be realized. The present fertilizer marketing system is loosely structured and restrains fertilizer use. The major constraints identified were: unavailability of a timely supply, inadequate roads and transportation system, lack of educational programs, high fertilizer prices, and lack of government support, especially in guaranteed crop prices and organized markets for produce.

The study pointed out a need to determine the most appropriate fertilizer for the principal crops by major ecological zones and soil types. The development of response curves and benefit:cost ratios using modern trial design and statistical and economical analyses for farm-level evaluation is needed, particularly for food crops.

The study team recommended that the use of high-analysis bulk straight fertilizer and bulk-blended NPK fertilizers be considered because this could be less expensive than shipping, transporting, handling, and bagging the imported low-analysis granular NPK fertilizers and ammonium sulfate currently being used.

The study, when completed, should establish the most appropriate type and quantities of fertilizers needed for principal crops, the possibilities of a bulk blending and bagging plant for an economical source of fertilizer supply, and the modification in the present marketing system necessary to overcome the marketing constraints and make it cost effective and efficient.

Asia

Study of Research and Design Institutes of China Fertilizer Development Center

In early 1984 the People's Republic of China established the China Fertilizer Development Center (CFDC). The CFDC is the planning/coordinating body for eight existing fertilizer research and design institutes. A program was developed to strengthen the CFDC and the institutes through procurement of new research equipment, computer hardware/software, and training. An IFDC engineer participated in a World Bank mission to advise the CFDC and member institutes in the above categories.

Malaysian FPM Sendirian Berhad Granulation Project

The FPM plant, developed with IFDC assistance, has achieved a level of routine operation. An IFDC engineer provided some onsite training for the plant management and operating staff. The engineer gave FPM advice on methods to overcome the adverse physical properties that are inherent in urea-based NPK products, especially those products that contain water-soluble magnesium.

Assistance to Philippine Phosphate Fertilizer Corporation

IFDC continued to assist the Philippine Phosphate Fertilizer Corporation (PHILPHOS) in activities leading to domestic production of phosphate fertilizer. Five onsite IFDC consultants are in the Philippines to advise PHILPHOS on plant construction and operation. Through PHILPHOS funding, IFDC supplied to that company a continuous bench-scale wet-process phosphoric acid and a companion acid concentration unit. IFDC also procured for PHILPHOS a complete pilot system for flotation-type beneficiation, which should be installed in 1985. The company will use the equipment for training and to evaluate local ores and ore mixtures for phosphoric acid production.

Latin America

Startup of Pipe-Cross Reactor in Brazil

At the request of Quimbrasil, an IFDC engineer and a TVA engineer traveled to Brazil to assist in the startup of a pipe-cross reactor (PCR) modification to an existing NPK plant. The project began in late 1982 when IFDC and TVA agreed to assist Quimbrasil in the design, installation, and startup of the PCR modification. The successful startup in April 1984 was the culmination of the project.

Three weeks were spent at the Quimbrasil plant during the startup operational tests. The plant with the new PCR modifications was operated to produce a series of NPK grades requested by Quimbrasil. Fuel savings of up to 70% were reported for some grades.

Fertilizer Status Profile of Ecuador

To assist the Government of Ecuador (GOE), the U.S. Government sent to Ecuador a Presidential Task Force to identify areas in agriculture where U.S. assistance would be most beneficial to that country.

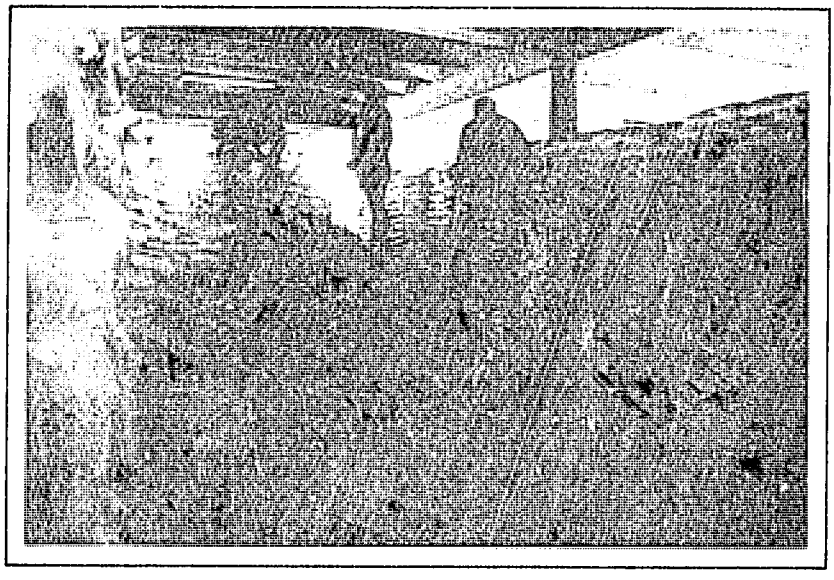
In preparation for that visit, USAID requested IFDC to send a soil scientist and a fertilizer marketing specialist to Ecuador to prepare a report for the Task Force. The report was expected to identify the major problems preventing the increased use of fertilizer and therefore increased crop production.

The problems facing the GOE are severe, and this is particularly the case when the task is to improve the productivity of the small farmers. Several major constraints were identified by the IFDC mission, and the steps that must be taken to overcome these constraints were outlined.

Marketing Study for Venezuela

During 1984 IFDC performed a fertilizer supply, marketing, and distribution study for Petroleos de Venezuela, S.A. (PDVSA). PDVSA's responsibilities for administering the nation's oil industry include the production and marketing of fertilizers by its subsidiary, Petroquimica de Venezuela, S.A. (PEQUIVEN), and the latter's marketing affiliate PALMAVEN, S.A.

This study served to update an earlier, comprehensive fertilizer supply strategy study, which IFDC conducted for PDVSA in 1981. The intervening years witnessed significant changes in both the national economy and the fertilizer sector. The most notable of these included a substantial improvement in PEQUIVEN's fertilizer production capability and the abrupt removal of the longstanding fertilizer subsidy, in 1981, which raised fertilizer prices by as much as 300% and led to a decline



Venezuelan workers load fertilizer onto a trailer.

in usage by about 30%. The fertilizer subsidy, in the form of a 50% reduction in fertilizer retail prices, was reintroduced in March 1984. Also, in the interval between the 1981 and 1984 studies, PALMAVEN assumed the fertilizer marketing function previously handled by VENFERCA, an agency of the Ministry of Agriculture. PALMAVEN, which marketed fertilizers to farmers mainly through its network of regional warehouses, was in the trial stages of changing to a private-dealer marketing system.

As a consequence of a precarious financial situation, induced by lowered revenues resulting from the growing world oil surplus, Venezuela is placing more emphasis on stimulating domestic agricultural output as a means of reducing imports and stemming the outflow of foreign exchange. IFDC's latest study was particularly timely since it dealt with the role of fertilizer in increasing agricultural output. Its overall goal was to develop a strategy for expanding the demand for and increasing the efficiency of fertilizer use through the application of more cost-effective domestic production and marketing systems; the latter would emphasize assistance to farmers in fertilizer use. To that end, the study team projected fertilizer demand for the period 1984-93. It assessed the types, sizes, and locations of fertilizer production facilities needed to satisfy the projected demand. The team evaluated the marketing and distribution system to find ways to improve its operational and cost efficiency while providing farmers with fertilizers and fertilizer-use knowledge necessary to derive maximum economic benefits from using fertilizer.

Fertilizer Demand

Using statistical regression models in which demand was related to cropped acreage, fertilizer prices, crop prices, agricultural credit, and irrigated acreage, the IFDC team projected fertilizer demand. Projections were made for three scenarios—representing high, low, and most likely cases.

Fertilizer Supply

The study team determined that PEQUIVEN's NPK granulation plant lacked the capacity to satisfy the projected demand after 1985. Consistent with the recommendations of IFDC's 1981 study, the team felt that the projected demand can best be met by converting the present manufacturing facilities to the production of high-analysis blended fertilizers instead of granulated NPK fertilizers, which are now being made.

The IFDC study evaluated the physical and chemical characteristics of the raw materials needed for the manufacture of blended fertilizers and made cost estimates for converting the present NPK production facilities at Moron to the manufacture of blended fertilizers. A separate production and distribution cost study concluded that it would be more economical to produce blends at a single, centrally located production unit at Moron rather than at four smaller regional blending plants.

Fertilizer Marketing

A technical and economic evaluation of alternative marketing systems indicated that the private-dealer marketing system proposed by PALMAVEN, if properly implemented, would provide expanded market coverage in a more cost-effective manner and promote increased and more efficient fertilizer use when compared with PALMAVEN's zonal warehouse sales system.

To expand sales and enhance the efficiency of fertilizer use in a manner that would ensure maximum economic benefit to farmers, the study suggested that technical assistance to farmers should be increased through dealers and in cooperation with government organizations and farmer associations engaged in extension and farmer assistance. The study recommended strengthening of sales promotion and advertising programs based on tested agronomic principles. An organizational structure, including functions and responsibilities, of a technical services-oriented, dealer-based marketing system was developed. Principles and guidelines for preparing and implementing an overall plan for the proposed marketing system were also presented.

Training Programs

IFDC's training programs are designed to develop the technical knowledge and managerial skills of developing-country personnel in all aspects of fertilizer production, marketing, and use. These programs are adapted to the specific needs of individuals, organizations, governments, or sponsoring agencies interested in fertilizer-sector development. Training programs are conducted for groups and individuals, both on a regional basis and at IFDC Headquarters. These programs draw on the experience of IFDC's multidisciplinary team of engineers and marketing specialists to provide stimulating and innovative training sessions. Training programs are developed for personnel in all phases of fertilizer sector operation, including production and plant managers, maintenance engineers and supervisors, marketing specialists, and research workers.

In 1984 IFDC conducted eleven group training programs; six of these programs were held regionally, and five were held at Headquarters (Table 4). Training was provided to 235 participants in group training programs and 23 participants in individual training programs from 45 developing countries (Figure 16).

Table 4.
Summary of IFDC 1984 Training Programs

Program	Location	Duration	Number of Participants	Countries Represented
Group Training				
Marketing				
Fertilizer Marketing Management Training Program	Headquarters	6 weeks	20	Bangladesh, Burma, Egypt, India, Jordan, Malawi, Mexico, Nigeria, Pakistan, the Philippines
Use of Microcomputers for Fertilizer Sector Personnel	Headquarters	2 weeks	9	Bangladesh, Colombia, India, Indonesia, Pakistan, Sri Lanka
Statistics and Economics of Fertilizer Use	Headquarters	2 weeks	14	Bangladesh, People's Republic of China, Colombia, Guyana, India, Indonesia, Saudi Arabia, Sri Lanka, the Philippines
Fertilizer Distribution and Handling Training Program	India, Singapore, Indonesia	17 days	22	Bangladesh, Bhutan, Burma, India, Indonesia, Sri Lanka, Thailand, Zimbabwe
Regional Fertilizer Marketing Training Program for the Asian Region	Thailand	12 days	34	India, Indonesia, Malaysia, Nepal, Pakistan, Republic of Korea, Saudi Arabia, Sri Lanka, Thailand
Production				
Maintenance and Production Management Training Program	Headquarters; Baton Rouge and New Orleans, Louisiana, U.S.A.	17 days	27	Brazil, Egypt, India, Indonesia, Jordan, Pakistan, United Arab Emirates, Venezuela, Israel
Fertilizer Efficiency Research				
Fertilizer Efficiency Research in the Tropics—Africa (in French)	Mali	2 weeks	16	Burkina Faso, Central Africa, Mali, Niger, Senegal, Togo
Fertilizer Efficiency Research in the Tropics—Latin America (in Spanish)	Colombia	3 weeks	33	Bolivia, Colombia, Costa Rica, Dominican Republic, Ecuador, Guyana
IFDC/USDA/Auburn Soil Testing, Soil Classification, and Fertility Management Training Program	Headquarters	3 days	10	Bangladesh, Indonesia, Kenya, Mexico, Peru, Sierra Leone, Somalia, Sri Lanka, United States
National Programs				
Fertilizer Efficiency Research for Bangladesh	Joydebpur, Bangladesh	3 weeks	32	Bangladesh
Fertilizer Marketing Management for Bangladesh	Bangladesh	2 weeks	31	Bangladesh
Individual Training				
Fertilizer Production and Research	Headquarters	-	23	Bangladesh, Brazil, China, Egypt, Grenada, Indonesia, Kuwait, the Netherlands, Tunisia
Study Tours of Fertilizer Plants	Various plants in the United States	-	6	People's Republic of China
Fluid Fertilizer Plant Tours	Various plants in the United States	-	2	Mexico

Marketing

IFDC marketing programs focus on the identification of fertilizer needs of farmers and the functions and activities required to fulfill the identified needs. These programs are aimed primarily toward eliminating or partially removing the constraints to fertilizer use.

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 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 today's changing world. IFDC's marketing programs are designed to meet this need for the development of skilled fertilizer marketing personnel.

During 1984 IFDC held five marketing training programs, two of which were held in developing countries. During these programs 99 participants received training in various phases of fertilizer marketing.

Two new programs were offered during 1984: "Use of Microcomputers for Fertilizer Sector Personnel" and "Statistics and Economics of Fertilizer Use."

In addition to lecture and discussion sessions, many of the training programs provide opportunities to engage in hands-on activities in various aspects of fertilizer marketing. To gain practical information, participants in most of the training programs see marketing in action during field trips to various points of interest.

Participants in an IFDC computer training program complete an assigned exercise.

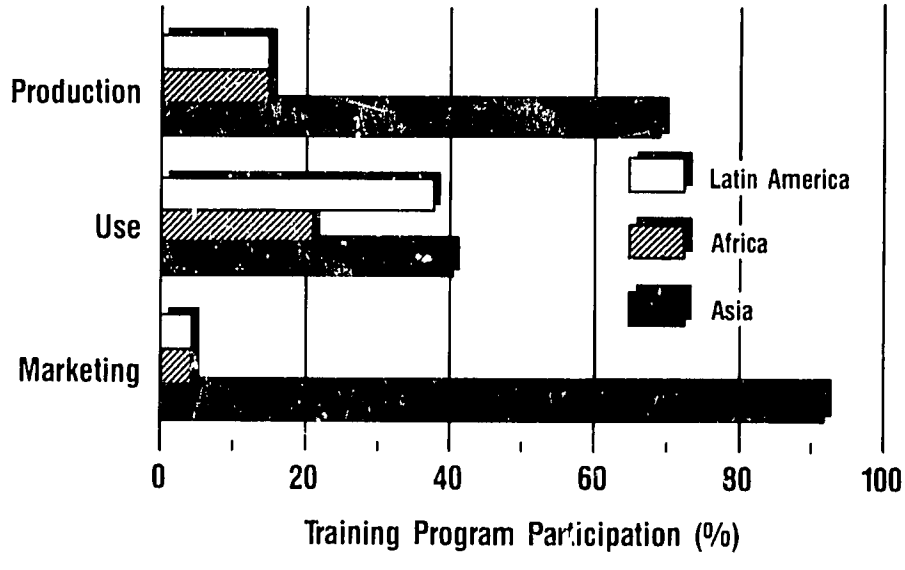


Figure 16. Distribution of IFDC 1984 Group Training Participants by Region of Origin and by Type of Program.

Production

IFDC's fertilizer production training programs focus on training developing-country plant personnel in fertilizer production and the maintenance and efficient operation of fertilizer plants.

During 1984 one program was offered: "Maintenance and Production Management." This was the fifth annual program of this nature. The first week of the program, held at IFDC Headquarters, provided an overview of the fertilizer sector including such topics as fertilizer supply and demand, production economics, and fertilizer production technology and research activities. The following 2 weeks were spent in the Baton Rouge and New Orleans, Louisiana, U.S.A. area and included a 3-day shortcourse on the operation and maintenance of ammonia/urea plants. This portion of the program provided participants with pragmatic and practical information about the industry. The information was presented in panel discussions led by representatives of the main international and U.S.-based fertilizer production organizations involved in ammonia and urea production.

Dr. Lawrence Mann, Jr., visiting instructor in the Maintenance and Production Management Training Program, makes a point.

Use

The goal of the programs focusing on fertilizer use is to help developing countries strengthen national field research programs that are directed toward improving the fertilizer practices followed by farmers. Emphasis is placed on helping the small farmer to increase crop yields by using fertilizer more efficiently.

The program agenda includes both theoretical and practical aspects of fertilizer efficiency research. Emphasis is placed on: (1) specific procedures for conducting fertilizer trials with new or improved fertilizer materials and application techniques and (2) agronomic, statistical, and economic analyses of results. One-half of the training time is

M. Bagayoko (left), Agronomist and a counterpart on the Mali Phosphate Project, explains how to collect information from an experiment to FERITT participants, Kokoasse Kpomblekou-Ademawou and Abdoulaye Traore.

devoted to classroom sessions and one-half to laboratory, greenhouse, and hands-on field activities. Practical fieldwork requires the design and installation of field research plots. All participants harvest and measure crop response and calculate economical statistical evaluation of the fertilizers tested. They prepare and present a technical report on their experiments.

During 1984, 59 agricultural research workers were trained in IFDC's fertilizer efficiency research training programs. One of these programs was conducted in Spanish in Colombia and one in French in Mali. A third program—"Soil Testing, Soil Classification, and Fertility Management," administered by the U.S. Department of Agriculture through Auburn University, Auburn, Alabama, U.S.A., entailed several days of presentations by IFDC staff members at Headquarters.

Individual Training

IFDC designs individualized training programs for governments, institutes, and companies involved in fertilizer-sector development and operation. Curriculum, location, and duration vary with individual requirements and available resources and are specifically tailored for each individual or small group.

The technical assistance work accomplished by IFDC has always included a substantial training component. Whether the project includes transfer of technology such as introduction of the pipe-cross reactor or assistance in improving existing plant operation, the element of training local personnel in new or improved techniques is always present.

The individual program curricula in 1984 included bulk-blending, bench-scale phosphoric acid production, phosphate ore beneficiation, advanced laboratory techniques, computer calculations, soil fertility research, soil fertility evaluation, fluid fertilizer manufacture and application, fertilizer production techniques, and fertilizer dealer development and promotion. A total of 23 individuals participated in IFDC individual training programs and represented the following 10 countries: Bangladesh, Brazil, China, Egypt, Grenada, Indonesia, Kuwait, Mexico, the Netherlands, and Tunisia.

In addition to special programs developed at IFDC Headquarters for individuals, study tours were organized for the purpose of visiting manufacturing and research facilities in the United States. One such study tour was arranged for six scientists from the Chinese National Chemical Construction Corporation in July 1984. The objectives of the tour were to observe state-of-the-art technology for production and application of fluid fertilizer, including anhydrous ammonia. The group arrived in California and toured southwestern United States, visiting fluid fertilizer plants. The second week was spent at IFDC/TVA Headquarters; visits were made to application equipment manufacturers and small-scale fluid fertilizer producers. The last week was spent touring major facilities in the Midwest and on the east coast of the United States before the group returned to China.

A similar but shorter study tour program on fluid fertilizers was also developed for two engineers from Mexico who represented the Secretariat of Energy, Mines, and Industry.

Evaluation

With a strong commitment to improving its training programs to better meet the needs of the personnel in the developing world's fertilizer sector, IFDC recognizes that evaluation is a necessary and integral part of its training effort.

Evaluation has been incorporated as a part of all training programs at IFDC. It provides feedback on the conduct of a program and also serves as a valuable tool in future program planning. The evaluation form measures participants' reactions to their total training experience. Participants are invited to give their candid comments on what they like and/or dislike in the program and suggest changes or modifications.

The assessment questionnaire surveys the participants' individual objectives when they first arrive for a training program. Information from this questionnaire is immediately processed and incorporated into the program whenever appropriate.

The baseline/followup exercise measures the participant's knowledge and skills acquired during the program. The baseline exercise is given at the beginning of the program, and the same questionnaire is administered as a followup exercise at the end of the program. The change in the score between the baseline and followup exercises provides one indication of the effectiveness of the training and methods used.

Financial Report

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

March 13, 1985

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, 1984 and 1983, and the results of its operations and changes in its fund balances for the years then ended in conformity with generally accepted accounting principles consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Price Waterhouse

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

ASSETS

CURRENT FUND

	December 31, 1984	December 31, 1983
Cash	$ 80,279	$ 416,636
Certificates of deposit	1,457,604	1,271,817
Amounts receivable from donors (Notes 1 and 2)	3,587,681	3,497,299
Other accounts receivable	777,468	1,133,205
Advances to employees	81,548	62,425
Supplies inventory (Note 1)	152,270	144,777
Prepaid expenses	158,927	187,652
	$6,295,777	$6,713,811

NONCURRENT FUND

	December 31, 1984	December 31, 1983
Amounts receivable from donors (Notes 1 and 2) - restricted	$1,065,000	$1,775,000

BUILDINGS AND EQUIPMENT FUND
(Note 1)

	December 31, 1984	December 31, 1983
Buildings	$5,734,995	$5,734,995
Equipment	4,811,804	4,235,178
Less - Accumulated depreciation	(4,025,067)	(3,450,178)
	$6,521,732	$6,519,995

LIABILITIES AND FUND BALANCES

CURRENT FUND

	December 31, 1984	December 31, 1983
Bank overdraft	$ 135,128	
Accounts payable	246,521	$ 315,369
Accrued annual and sick leave	1,361,050	1,221,946
Deferred revenue (Notes 1 and 2)	3,587,681	3,497,299
Total liabilities and deferred revenue	5,330,380	5,034,614
Fund balance -		
Restricted	319,479	172,132
Unrestricted	645,918	1,507,065
	965,397	1,679,197
	$6,295,777	$6,713,811

NONCURRENT FUND

	December 31, 1984	December 31, 1983
Deferred revenue (Notes 1 and 2) - restricted	$1,065,000	$1,775,000

BUILDINGS AND EQUIPMENT FUND
(Note 1)

	December 31, 1984	December 31, 1983
Contract retainage	$ 412	$ 392
Fund balance	6,521,320	6,519,603
	$6,521,732	$6,519,995

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1984 AND 1983

	Current Fund		Buildings and Equipment Fund		Total All Funds	
	1984	1983	1984	1983	1984	1983
Revenue:						
Grants (Note 2)	$7,196,032	$5,576,119			$ 7,196,032	$5,576,119
Recovered project costs	2,048,107	2,781,425			2,048,107	2,781,425
Other	143,689	149,865			143,689	149,865
Total revenue	9,387,828	8,507,409			9,387,828	8,507,409
Expenses:						
Research	4,907,007	4,703,394	$ 496,183	$ 473,072	5,403,190	5,176,466
Outreach	2,360,525	2,086,144	47,220	41,085	2,407,745	2,127,229
General and administrative	2,198,368	1,810,093	90,608	89,661	2,288,976	1,899,754
Total expenses	9,465,900	8,599,631	634,011	603,818	10,099,911	9,203,449
Excess (deficiency) of revenue over expenses	(78,072)	(92,222)	(634,011)	(603,818)	($ 712,083)	($ 696,040)
Other changes in fund balances:						
Equipment acquisitions from unrestricted funds	(635,728)	(47,061)	635,728	47,061		
Fund balances, beginning of period	1,679,197	1,818,480	6,519,603	7,076,360		
Fund balances, end of period	$ 965,397	$1,679,197	$6,521,320	$6,519,603		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1984 AND 1983

	Research		Outreach		General and Administrative		Total Expenses	
	1984	1983	1984	1983	1984	1983	1984	1983
Personnel compensation (Note 3)	$2,382,670	$2,477,378	$1,197,261	$1,063,802	$1,165,032	$1,018,683	$4,744,963	$4,559,863
Personnel benefits (Note 3)	398,098	389,872	225,602	202,178	257,024	167,059	880,724	759,109
Travel and transportation	323,445	306,718	318,990	334,135	171,155	145,749	813,590	786,602
Occupancy	262,203	228,146	115,232	111,225	118,146	131,254	495,581	470,625
Telephone and telegraph	55,456	48,381	49,405	28,675	28,336	19,717	133,197	96,773
Rental of equipment	29,680	34,217	17,564	21,232	30,506	15,870	77,750	71,319
Contractual research and development	574,496	492,618	28,215	55,398			602,711	548,016
Other contractual services	270,632	300,847	183,200	134,628	192,314	142,376	646,146	577,851
Institute of International Education fee (Note 3)					90,116	93,102	90,116	93,102
Materials and supplies	568,758	378,741	204,271	111,632	124,955	53,044	897,984	543,417
Postage	16,385	18,003	8,193	9,002	8,193	9,002	32,771	36,007
Insurance	25,184	28,473	12,592	14,237	12,592	14,237	50,368	56,947
Miscellaneous	11,295	4,813	(1,157)	(665)	2,354	468	12,492	4,616
Total expenses before depreciation	4,918,302	4,708,207	2,359,368	2,085,479	2,200,723	1,810,561	9,478,393	8,604,247
Depreciation of buildings and equipment	484,888	468,259	48,378	41,750	88,253	89,193	621,519	599,202
Total expenses	$5,403,190	$5,176,466	$2,407,746	$2,127,229	$2,288,976	$1,899,754	$10,099,912	$9,203,449

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF CHANGES IN CASH AND CERTIFICATES OF DEPOSIT

	Year ended December 31, 1984	1983
Balances at beginning of year:		
Cash	$ 416,636	$ 301,176
Certificates of deposit	1,271,817	1,653,574
	$1,688,453	$1,954,750
Cash was provided by:-		
(Deficiency) of revenue over expenses	($ 712,083)	($ 696,040)
Charges not requiring (providing) an outlay of cash:		
Depreciation	621,519	599,202
(Gain) loss on disposal of equipment	12,492	4,615
Increase in accrued annual and sick leave	139,104	186,794
Cash provided from operations	61,032	94,571
Proceeds from sale of equipment	4,471	100
Proceeds from issuance of short-term debt		300,000
Net decrease in other accounts receivable	355,737	
Net decrease in prepaid expenses	28,725	
Net increase in bank overdraft	135,128	
Net increase in accounts payable and contract retainages		6,972
	585,093	401,643
Cash was used for:		
Purchase of buildings and equipment	640,219	40,491
Reduction of short-term debt		300,000
Net increase in other accounts receivable		295,116
Net increase in advances to employees	19,123	10,379
Net increase in supplies inventory	7,493	7,788
Net increase in prepaid expenses		14,166
Net decrease in accounts payable and contract retainages	68,828	
	735,663	667,940
Net increase (decrease) in cash	($ 150,570)	($ 266,297)
Balances at end of year:		
Cash	$ 80,279	$ 416,636
Certificates of deposit	1,457,604	1,271,817
	$1,537,883	$1,688,453

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.

NOTE 2 - GRANTS:-

Grants are summarized as follows:

	Year ended December 31,			
	1984		1983	
	Restricted	Unrestricted	Restricted	Unrestricted
Grants received -				
United States Agency for International Development (AID)	$ 250,000	$4,000,000		$4,000,000
International Fund for Agricultural Development (IFAD)	1,100,000		$1,000,000	
Australian Development Assistance Bureau (ADAB)	147,112	188,560		175,300
International Development Research Centre (IDRC)	814,742			
Ford Foundation		76,000		
Phillipines				7,800
	2,311,854	4,264,560	1,000,000	4,183,100
Unexpended grants reverting to grantee			(500,000)	
Amounts deferred during prior year	2,917,299	2,355,000	4,265,318	1,900,000
	5,229,153	6,619,560	4,765,318	6,083,100
Less - Amounts deferred to future periods	2,892,110	1,760,571	2,917,299	2,355,000
Revenue recognized in current period	$2,337,043	4,859,989	$1,848,019	3,728,100
		2,337,043		1,848,019
Total restricted and unrestricted		$7,196,032		$5,576,119

The unrestricted grant from AID was amended to provide additional funds of $4,000,000 during each of the years ended December 31, 1984 and 1983, and to extend the grant period from June 30, 1984 to June 30, 1985. The unrestricted ADAB grants in 1984 and 1983 were gifts of funds recognized as revenue in the year received. The 1984 restricted ADAB grant represents additional funding for a project in Southeast Asia.

Restricted grants from AID, IFAD and IDRC were restricted by the grantor as to specific projects and geographic regions. The IFAD grants, $1,100,000 in 1984 and $1,000,000 in 1983, provided funds for the second and third years of a three year IFDC research program in Africa. The termination date of the grant was extended to March 31, 1985. The IDRC grants in 1984 provided funds for research projects in Latin America, to be completed November 30, 1986, and West Africa, to be completed November 30, 1985. Any grant funds not expended at the grant expiration date will revert to the grantor.

Receivables from donors and deferred grant revenue at December 31, 1984 and 1983 are summarized as follows:

	December 31,			
	1984		1983	
	Restricted	Unrestricted	Restricted	Unrestricted
AID	$ 222,829	$1,692,171		$2,355,000
UNDP	1,775,000		$2,485,000	
IFAD	200,000			
ADAB			320,762	
IDRC	694,281		111,537	
Ford Foundation		68,400		
	2,892,110	1,760,571	2,917,299	2,355,000
Less - noncurrent portion	(1,065,000)		(1,775,000)	
	$1,827,110	1,760,571	$1,142,299	2,355,000
		1,827,110		1,142,299
Total restricted and unrestricted		$3,587,681		$3,497,299

The UNDP grant provided funds for various research and outreach projects for grant periods of more than one year. The UNDP grant expires in 1987. Funds relating to this grant receivable not budgeted for expenditure in 1985 and 1984 are classified as noncurrent at December 31, 1984 and 1983, 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.

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

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

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