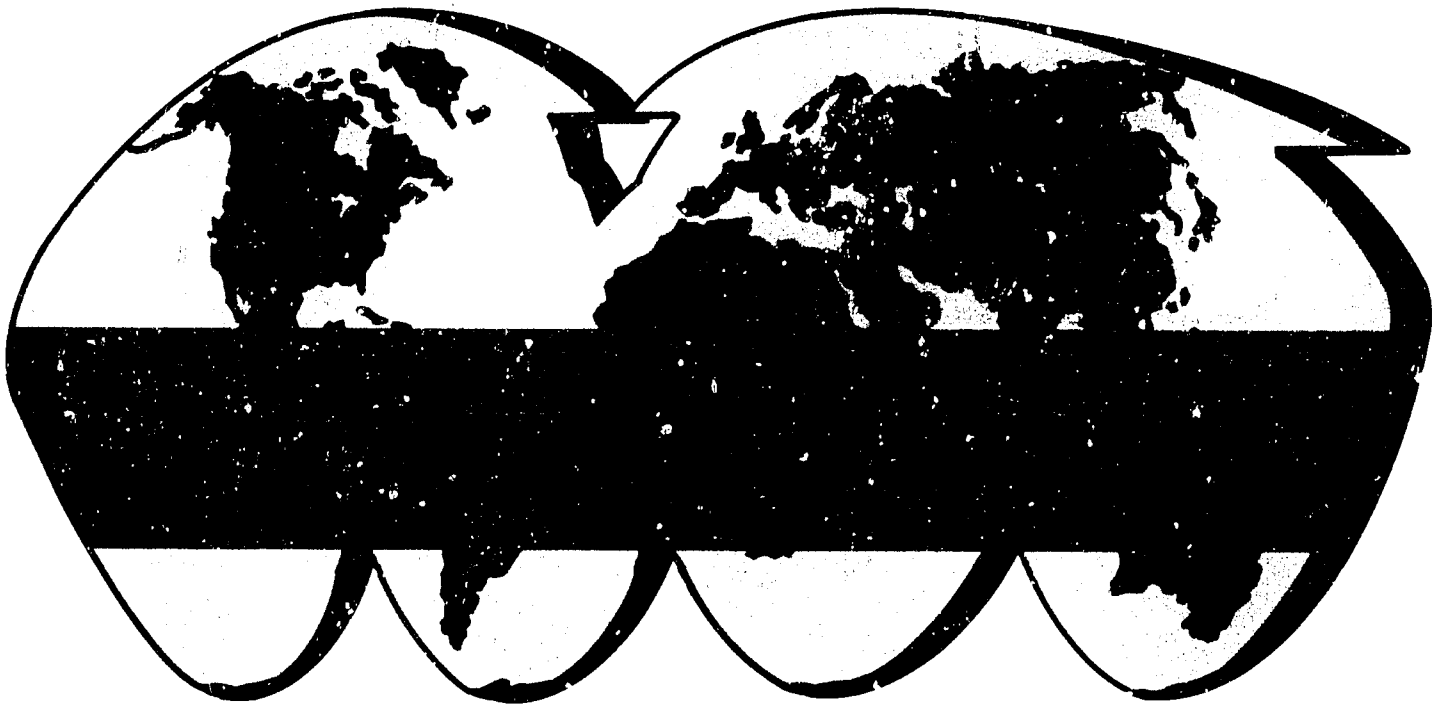
IFDC Annual Report 1980



Striving to Feed
A Hungry World

IFDC Profile

Creation and Mission

The world food crisis of the early 1970s provided the impetus for the creation of an international fertilizer research center to focus on the development of appropriate fertilizer technology and related know-how to increase food production in the developing countries, especially those of the tropics and subtropics. The U.S. Secretary of State, in a speech before the United Nations General Assembly in April 1974 urged the establishment of this center. The center that evolved is today known as the International Fertilizer Development Center (IFDC). On October 7, 1974, IFDC was officially registered in the State of Alabama as a private, nonprofit corporation. On March 14, 1977, IFDC was designated as a nonprofit, public international organization.

Funding

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

Location

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

Board

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

Staff

The IFDC staff of 160, recruited from 19 countries, is diverse with almost half of this number being chemical engineers, chemists, economists, agronomists, geologists, soil scientists, and sociologists. IFDC is able to carry out and implement fertilizer research and development because of three complementary factors: (1) the multidisciplinary structure of the task teams used for research planning; (2) the ability to produce and test experimental fertilizers in laboratories, pilot plants, and greenhouses; and (3) linkages with fertilizer research institutions around the world.

Framework

IFDC has three divisions—Agro-Economic, Fertilizer Technology, and Outreach. The Office of the Managing Director is the administrative arm of IFDC. The Agro-Economic and Fertilizer Technology Divisions are research oriented and focus on the development of products and practices to solve immediate and long-term problems. The Outreach Division has the prime responsibility for information dissemination, as well as identification of problems of global to regional importance.

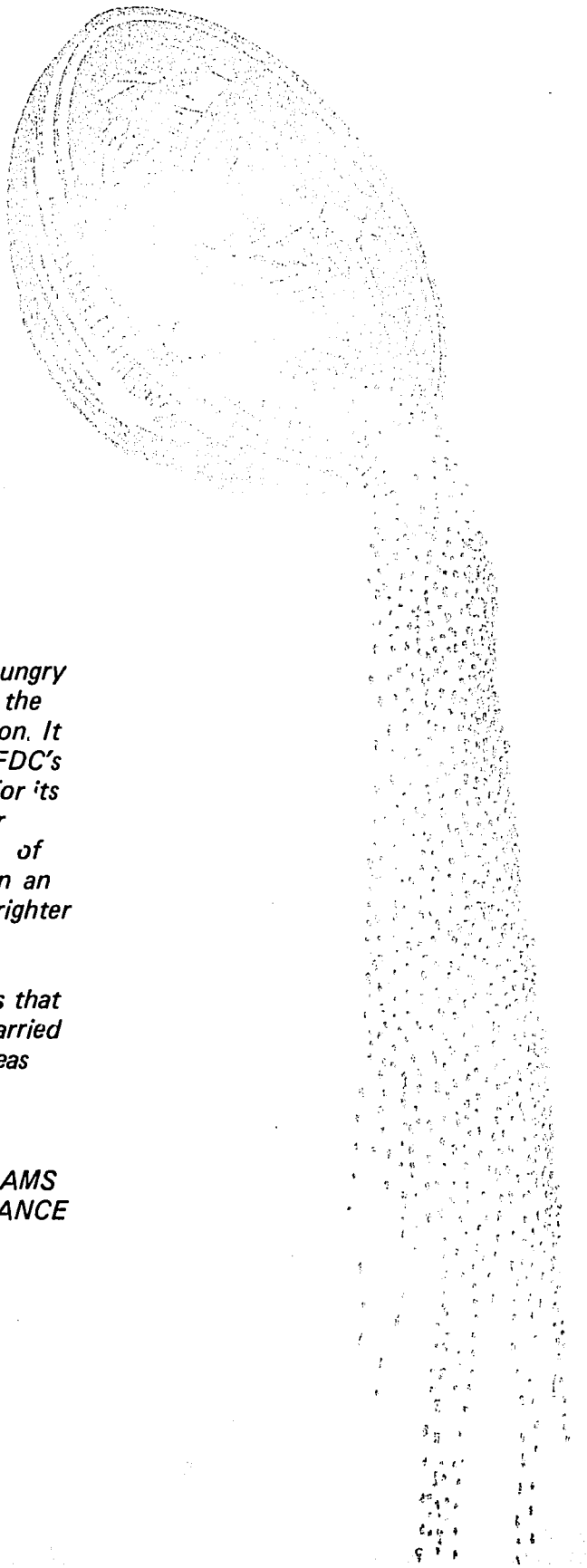
Facilities

The three divisions are backstopped by facilities that include laboratories; greenhouses; growth chambers; an electron microscope, a mass spectrometer, and other specialized equipment essential for laboratory research; pilot plants used in studies involving the beneficiation, acidulation, and granulation of fertilizers; and an audiovisual center and a word processing center capable of disseminating information through various media.

Linkages

IFDC recognizes that it cannot carry out its mission alone but that it requires assistance and cooperates with many international, regional, and national institutions. IFDC has specialists posted at a number of these institutions. Technology developed by IFDC scientists and engineers is tested under a wide range of conditions before its applicability can be established for given areas.

Striving to Feed a Hungry World



"Striving to feed a hungry world" is more than the theme of this publication. It strikes at the core of IFDC's being. It is the reason for its existence. This ther embodies the purpos of IFDC's reaching out in an attempt to make life brighter for the world's people.

As seen in the pages that follow, the theme is carried out in four broad areas of IFDC's endeavors:

RESEARCH
NATIONAL PROGRAMS
TECHNICAL ASSISTANCE
TRAINING

Managing Director's Report

The capacity of the human mind to cope with expanding knowledge is equal to the capacity of the mind to create it.

John A. Hannah, Chairman,
IFDC Board of Directors

In a time of rapid technological change, the most crucial force of research is this creative thought of which Dr. Hannah speaks. It is the hope of the world's future. In the destinies of the world's people, failure to foster creative thought will lead to stagnation.

IFDC is itself the embodiment of creative thought. It is a place, a staff, a facility, and a climate for change in the fertilizer research and development field. Finally, it represents a response to a need for an organization dedicated to the mission of feeding a hungry world through the development of improved fertilizers and fertilizer technology for the tropics and subtropics.

IFDC has entered the decade of the 80s with enthusiasm and determination to strive even more diligently to help solve the food shortage problems of the developing world.

Recognizing that people are the most valuable resource to be developed as part of the solution to world hunger, IFDC more than tripled the size of its training program from two programs in 1979 to seven in 1980. During 1980 a total of 226 participants received training in marketing, production, and fertilizer efficiency research. This expansion in training was made possible by a major grant from the United Nations Development Program (UNDP).

Technical assistance is another means that IFDC uses to transfer technology to developing countries. More than 760 requests for information or in-country assistance were handled during 1980.

Rapidly rising energy costs and inflationary conditions during 1980 have drastically increased the costs of fertilizers. From 1979 to 1980, the annual average price of urea increased by about 35%; ammonium sulfate, about 31%; triple superphosphate, about 22%; and muriate of potash, about 36%. These factors have created a sense of urgency in the field of fertilizer research. More efficient forms of fertilizer and more effective use practices must be developed if the world's people are to be fed.

Under its Nitrogen Research Program, IFDC intensified its efforts during 1980 toward determining the nitrogen use efficiency of major food crops grown under different agroclimatic conditions and toward identifying and measuring nitrogen losses. During 1980 IFDC continued to identify and prepare new or modified nitrogen materials that serve as more efficient nutrient sources to crops.

The steady rise in the cost of finished phosphates has caused developing countries to search for ways

to develop their indigenous resources. IFDC, through its Phosphate Research Program, has endeavored to help developing countries, such as Upper Volta and Colombia, develop their phosphate deposits.

IFDC realizes that it cannot accomplish its mission without the full partnership, commitment, and participation of key institutions within each developing country. In this light, national programs are being developed to provide a vehicle through which problems can be identified and technology can be tested as to its applicability to the developing country.

Through its efforts in research, training, national programs, and technical assistance, IFDC strives to build "bridges of understanding" between its Headquarters and developing countries so that food production can be increased and, in turn, the world's hunger problem can be reduced.

Donald L. McCune

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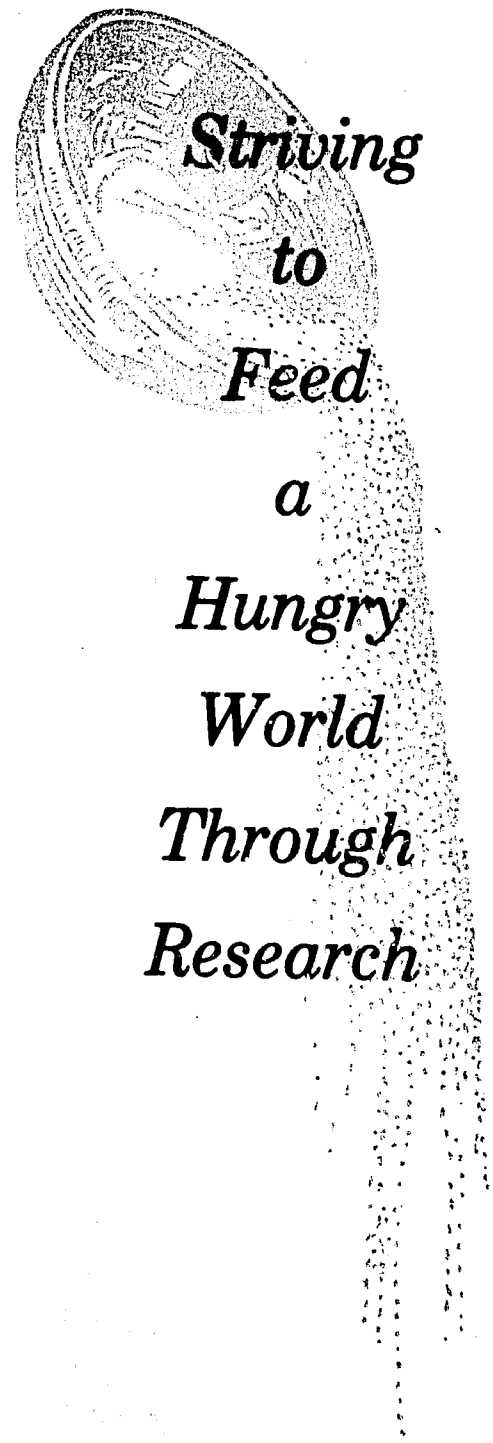
Research Program



An increasing world population, adverse weather, and land limitations all have contributed to the gravity of the world food crisis. The rapid increase in energy prices and subsequent impact on fertilizer prices, particularly during late 1979 and 1980, have given immediate urgency to the situation. IFDC is investigating the important role that fertilizers must play in solving this problem. Beginning with its inception in 1974, when the fertilizer sector was in a highly unstable period, IFDC has geared its programs toward assessing global trends in fertilizer use and their ramifications and toward developing new or improved fertilizers for developing countries, especially those in the tropics and subtropics.

The overall research program focuses on deriving solutions to problems related to nitrogen, phosphorus, and sulfur fertilizers and constraints to their use.

IFDC's Nitrogen Research Program is aimed at increased crop recovery from the nutrient applied. This goal must be achieved because the rising costs of capital and energy required to construct and operate modern nitrogen complexes have caused prices of nitrogen fertilizers to soar. Initial efforts have focused on reducing losses of nitrogen for rice grown under flooded conditions where recovery rates of less than 30% of nitrogen fertilizer are common. A three-phase program to correct this problem has been developed. It includes: (1) identification of the causes and magnitude of nitrogen losses, (2) development of practices and/or products that reduce these losses, and (3) implementation of this technology in given geographic areas. The Nitrogen Research Program was expanded in 1979 to study problems of nitrogen efficiency on upland crops.

The IFDC Phosphate Research Program also has the objective of improved fertilizers for tropical and subtropical areas, emphasizing effective use of indigenous ores. Phosphate ores from developing countries are characterized and technology for their use is evaluated through economic and agronomic studies.

Sulfur, which is deficient in many tropical and subtropical areas of the world, is another nutrient receiving attention. This research is now limited to studies of agronomic effectiveness of experimental versus conventional materials and to the development of techniques to determine soil deficiencies and responses.

Nitrogen Research

During 1980 a major thrust continued to be directed toward quantification of nitrogen use efficiency of major food crops grown under a range of agroclimatic conditions and toward identifying and quantifying the nitrogen losses from these soil/plant systems. Major efforts were directed toward identification of losses in lowland (flooded) systems and upland situations, particularly for the arid and semiarid zones of the tropics. This work was carried out at IFDC Headquarters and at appropriate locations in developing countries in collaboration with national institutions and with international agricultural research centers (IARCs).

During 1980 a major thrust continued to be directed toward quantification of nitrogen use efficiency of major food crops grown under a range of agroclimatic conditions and toward identifying and quantifying the nitrogen losses from these soil/plant systems.

The stable isotope ^{15}N, an invaluable tool in tracing the fate of fertilizer in the soil/plant system, was used in these experiments. Nitrogen transformations in the soil that may lead to nitrogen losses from the soil/plant system were studied in detail in an effort to find fertilizers or fertilizer management practices to prevent or minimize these transformations and thus reduce nitrogen loss from the system. This work was carried out for both upland as well as lowland crop systems.

Both product and process development studies constituted a significant part of the nitrogen program. Product development was carried out mainly in the laboratory. Process development of modified urea was done in the pilot plant. Many of the products developed are being tested in both the upland and lowland nitrogen programs.

NEW AND MODIFIED PRODUCTS

During 1980 IFDC continued its efforts to identify and prepare new or modified nitrogen fertilizer materials that serve as more efficient nutrient sources to crops. These materials were made available for agronomic research. The range of products was expanded to reflect a broadening of the agronomic research program. Urea is the main nitrogen source in many developing countries and, thus, received major attention.

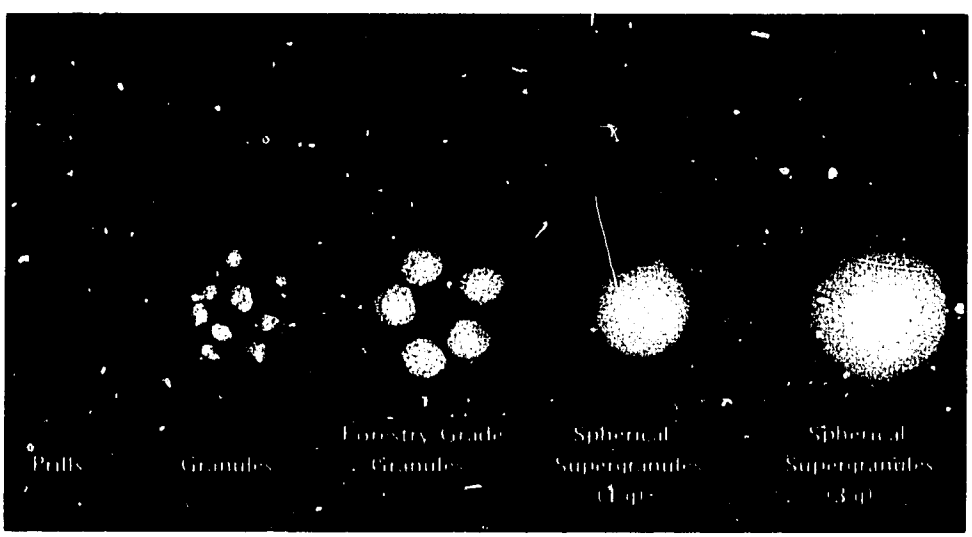
In addition to previous studies such as (1) coating urea particles of various shapes and sizes to control nitrogen release and (2) determining the relative efficiencies of high-analysis nitrogen compounds with limited water solubility, a new study of urease and nitrification inhibitors was started during 1980. Studies of inhibitors are expected to receive more emphasis in the future.

Urea Particle-Size Modification

Deep placement of ammoniacal sources of nitrogen such as urea increases nitrogen recovery by rice grown under flooded conditions. The technique is not new. It orginated in Asia as the "mudball" method. Mudballs containing organic, and later chemical, fertilizer were formed by hand and allowed to air dry and harden. During transplanting, the mudballs were deep placed in the reduced soil zone and between the rice plants. Although this technique improves fertilizer efficiency, production and deep placement of the mudballs are extremely labor-intensive operations. Thus, IFDC continued research to develop urea materials that are easier to produce and apply compared with mudballs. This has resulted in the development of large particles of urea, weighing from 0.25 to 2.00 g/particle, called supergranules.

When supergranules are placed at a depth of about 10 cm in the soil, the efficiency of nitrogen varies according to the crop and soil, but it is nearly double that of broadcast prilled urea.

Deep placement of urea in supergranular form is being evaluated as one method for improving the efficiency of nitrogen in rice cultivation as a replacement of the mudball technique. When supergranules are placed at a depth of about 10 cm in the soil, the efficiency of nitrogen varies according to the crop and



soil, but it is nearly double that of broadcast (surface applied) prilled urea.

IFDC is working closely with other firms in the development of urea supergranules. Special mention is made of Norsk Hydro of Norway and Nederlandse Stikstof Maatschappij (NSM) of the Netherlands, commercial nitrogen producers, that have supplied IFDC with experimental quantities of this material to carry out agronomic tests. However, to IFDC's knowledge 1-g or larger supergranules of urea are not commercially available in large quantities. Process development studies, initiated in 1979 by IFDC to produce conventional granular urea (0.01 g/particle) in a pan-granulation process, were successful. In addition, exploratory tests were begun to use the process for making larger particles (1.0-3.0 g/particle). IFDC produced additional experimental quantities of supergranules during 1980 by pan granulation to begin a technical and economic evaluation of commercial-scale production. Several methods of making supergranules were studied using a pan-type granulator. These methods differed primarily in the granulation temperature and in the percentage of onsize material recycled to the granulator. In all cases urea melt prepared from prills was sprayed on top of the rolling bed of recycled granules in the pan granulator. The material from the granulator passed through a rotary cooler and then to a screen where the product-size material was removed. The remainder was recycled to the granulator. No attempt was made to minimize biuret formation in these tests.

Results from the pilot-plant studies indicate the following:

1. Granules weighing about 0.25 g/particle can be routinely produced in a conventional pan-granulation process without major changes in equipment or operating procedures.
2. Granules weighing about 1.0 g/particle can be produced, but a major quantity (about 20% of the production) of smaller size granules (0.1-0.2 g/particle) also are produced as a coproduct.
3. A large amount of process dust is produced in all cases. This dust must be reprocessed and is the cause for unresolved technical problems relative to cost and the formation and removal of unwanted biuret in the product.

Future work will be directed toward determining: (1) alternative ways of producing urea supergranules (drum or fluidized-bed granulation, briquetting, or tableting); (2) methods for decreasing the amount of process dust; and (3) more definitive production costs.

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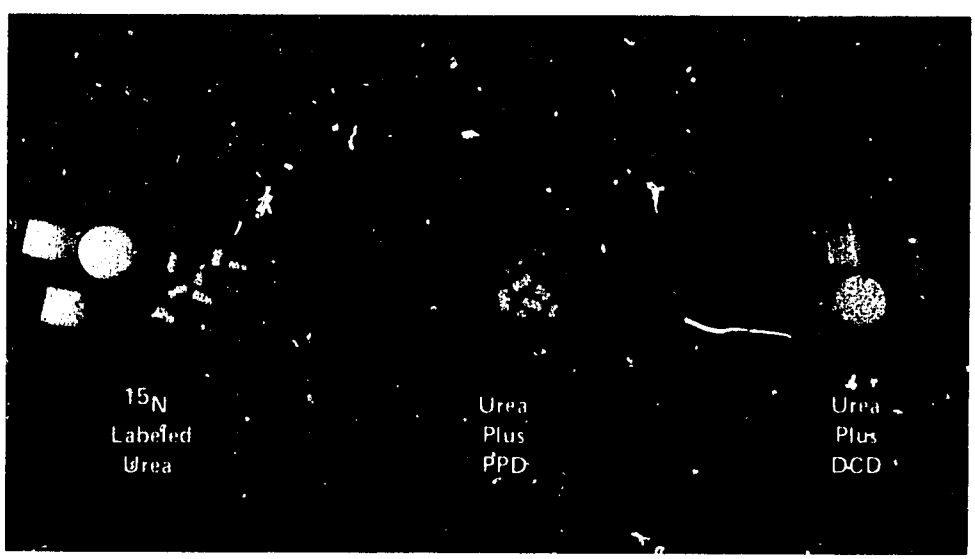
Coating of Soluble Fertilizer

Some developing countries are interested in the concept of coating soluble fertilizer such as urea to control nutrient release but prefer using locally available coating materials. IFDC intensified its search for indigenous materials that might be suitable coating materials. Materials, such as sodium alginate grafted copolymers, natural rubber latex, rice-bran wax, paraffin wax, silicate-latex polymers, polyanhydride resins, and a mixture of sealant and neem oil, were prepared and evaluated in the laboratory. The size fractions of urea used for coating were either forestry grade (0.10 g/particle, ≅5-mm diameter) or supergranules (1.0 g/particle, ≅11-mm diameter) with emphasis on supergranules that could be deep placed in rice paddies by hand or by machine. Four methods used for coating were: (1) individual particles were hand



Left—*These experimental and commercially available forms of urea are being used for agronomic evaluation. These include prills, granules, forestry-grade granules, and spherical supergranules.*

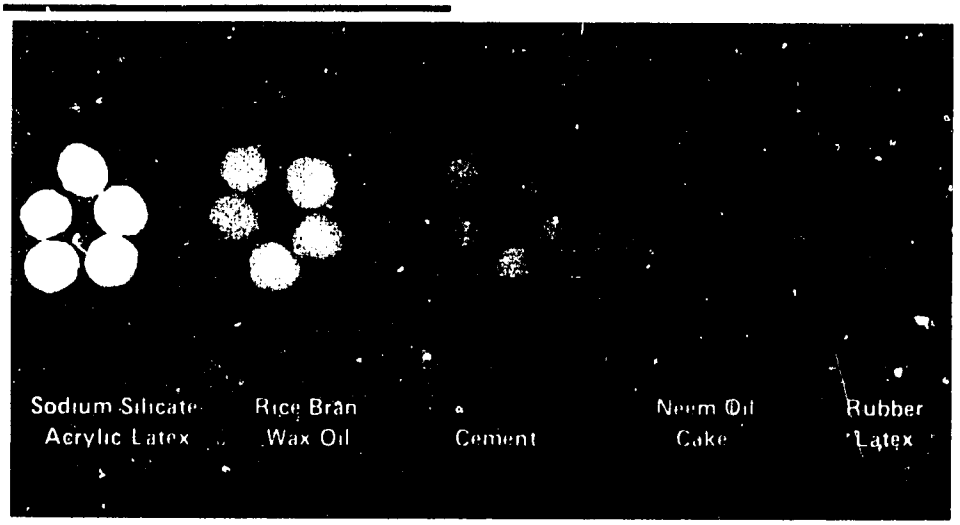
Right—*Tableting in various sizes is a convenient method for preparation of experimental nitrogen materials.*

dipped in the coating, (2) a solution or melt of the coating was sprayed in a rotary drum, (3) the coating solution was sprayed in a fluidized-bed system, and (4) the particle surface was melted and a fine powder was dusted on. A brief description of the rotary-drum and fluidized-bed systems is given.

IFDC intensified its search for indigenous materials that might be suitable coating materials.

Application Methods

Coating Urea in a Rotary Drum—With solutions or melts for spraying in a rotary drum, the materials consisted of pressurized nitrogen gas for spraying, a reservoir for coating material, a spraying system, and a variable-speed rotary drum (Figure 1). Pressure and temperature were monitored and controlled throughout the operation. The drum is equipped with internal lifting flights and a device that forms a curtain of falling urea particles. Spraying onto the falling curtain gives a more uniform coating compared with spraying onto a rolling bed. The falling-curtain principle is an adaptation of the one used in the TVA sulfur-coated urea (SCU) demonstration-scale plant. Approximately 4 kg of coated product is produced per batch. In some cases, a sealant and/or a conditioner is applied following the initial coating, usually in a separate coating drum of simple design. For this a variable-speed rotary drum without lifting flights is used.



Coating Urea in a Fluidized Bed—Both IFDC and the Korea Advanced Institute of Science and Technology (KAIST) of Seoul, South Korea, with whom IFDC has a collaborative program, have fluidized-bed equipment (Figure 2) for use in coating applications. The process is a batch operation that will fluidize a wide range of particle sizes. The coating solution is pumped inside the fluidizing chamber and sprayed by pressurized air at a controlled rate and temperature. Following the coating operation, the unit is opened and the product is recovered. KAIST has gained considerable experience in fluidized-bed operation during the production of a sodium silicate-acrylic latex product. IFDC has used the fluidized bed for the application of sodium alginate-grafted copolymers and some latex coatings.

Sodium silicate-acrylic latex polymer was used as a coating for urea to produce experimental quantities of fertilizer in collaboration with KAIST. A precoating of sodium silicate was applied to 0.1- to 1.0-g particles of urea, with or without silicate insolubilization. An acrylic latex polymer was applied over the silicate coating to achieve the controlled-release property. By varying the total coating, products having varying rates of nitrogen release, as measured by their dissolution in water, can be produced. Materials having three levels of nutrient release—high, medium, and low—were supplied to

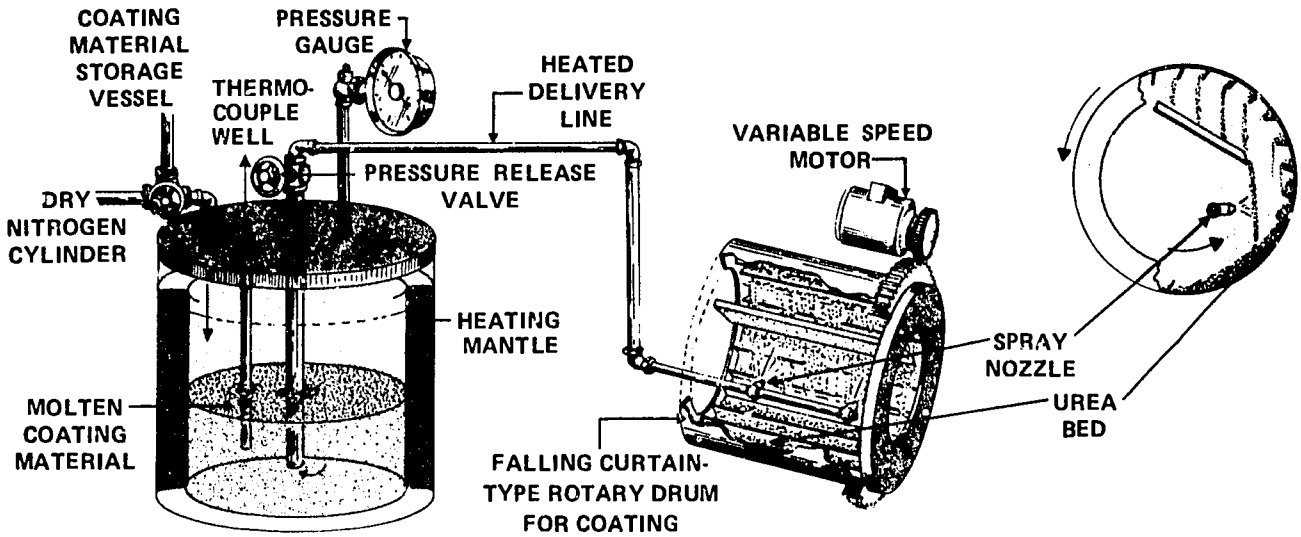


Figure 1. Bench-Scale Coating Equipment (Batch).

IFDC for agronomic evaluation, using forestry-grade urea as the substrate. KAIST is conducting additional experiments in an attempt to decrease the cost of coating by reducing the quantity of coating materials needed for a given dissolution rate. IFDC, with the help of a visiting scientist from Korea, also made sodium alginate copolymers (sodium alginate plus methyl methacrylate or acrylamide) and investigated them for coatings. The polymers must be insolubilized by reaction after application with divalent cations, such as calcium, magnesium, zinc, or copper.

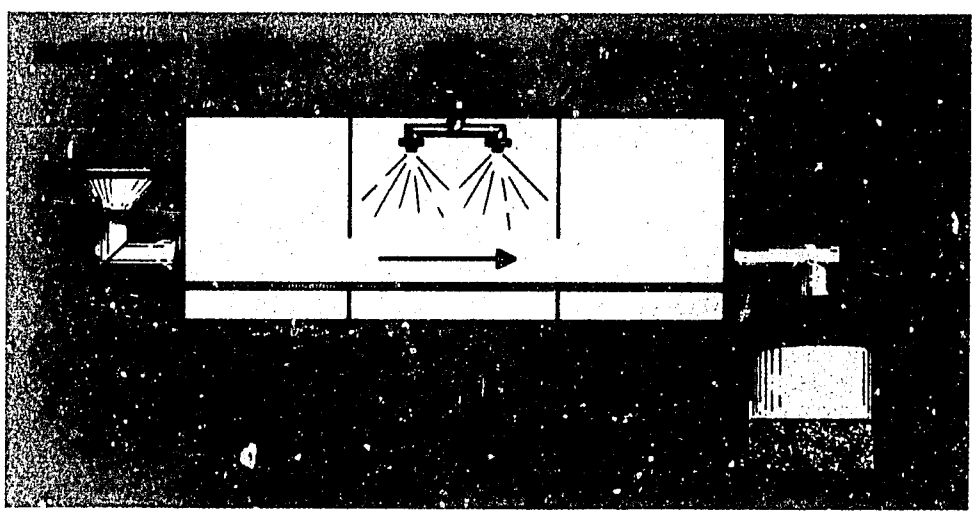
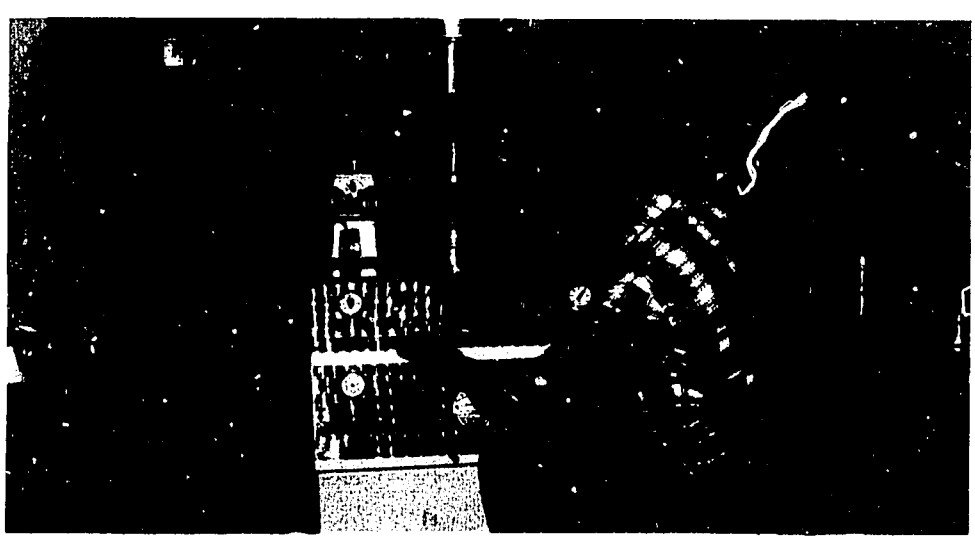


Figure 2. Bench-Scale Fluidized-Bed Coating Process.



Upper Left—*IFDC is evaluating a wide variety of materials for coating water-soluble nitrogen fertilizers. These include sodium silicate-acrylic latex, rice bran wax-oil, neem-oil cake, and rubber latex.*

Lower Left—*IFDC researchers are using this bench-scale modified rotary drum employing the falling curtain principle for coating of water-soluble nitrogen fertilizers.*

Lower Right—*A fluidized-bed coating process is being compared with the modified rotary drum process for coating.*

Evaluation of Physical and Chemical Properties of Coated Materials

IFDC conducted preliminary laboratory studies in 1980 to develop suitable test procedures for determining the nutrient release rate from individual coated supergranules in water and in lowland soil systems. Simultaneously, an attempt was made to study how urea release is influenced by coating materials. Two procedures to determine nutrient release rate in water were used. In Procedure 1, a 1-g coated supergranule of urea was placed in 200 ml of water and continuously shaken at 100-110 oscillations per minute at 38°C. The urea released to the outside solution was measured colorimetrically using p-dimethyl aminobenzaldehyde reagent. In Procedure 2, a 1-g coated supergranule of urea was placed in 15 ml of water and continuously shaken at 100-110 oscillations per minute at 38°C, and the urea released to the outside solution was determined from the refractive index of solution measured at 30°C. This is a relatively simple and rapid procedure that has been suggested for measuring the variation in urea release from individual supergranules having a nonswelling coating such as sulfur or wax.

IFDC conducted preliminary laboratory studies in 1980 to develop suitable test procedures for determining the nutrient release rate from individual coated supergranules in water and in lowland soil systems.

These procedures were used on SCU supergranules. The amount of urea released to the water from individual sulfur-coated supergranules having the same apparent coating varied significantly within a batch and between batches. For the purpose of quality control, it is necessary to report (1) variations among the individual SCU supergranules within a batch and (2) an average release rate for the material.

A simple technique for measuring the urea release from an individual deep-placed coated supergranule of urea in a lowland soil was developed (Figure 3). The artificial lowland soil system used in this technique simulates a physical-chemical and microbiological environment that would exist near the placement site of a coated supergranule of urea. Considerable variation in the urea released from individual coated supergranules was observed in the lowland soils. Data collected thus far indicate that the mechanism of urea release from individual coated supergranules in a lowland soil is very complex.

The nutrient release rates of a given product can possibly be affected by storage and handling conditions. Large particles are subject to breakage and the coating can be damaged during rough handling. Empirical tests are being developed by IFDC to study storage and handling effects on nutrient release. Coated nitrogen fertilizers for deep placement offer the best potential for improved efficiency where soils are highly leached. No products are now commercially available. Processing costs and the cost of raw material for coating increase the product cost.

Nitrogen Compounds of Limited Water Solubility

As part of the nitrogen research begun in 1979, tests were continued to prepare and agronomically evaluate selected nitrogen compounds exhibiting varying degrees of water solubility. This is promising as a method to control nutrient release through particle size and is an alternative to coating of soluble nitrogen fertilizers. Preparation of small quantities consisted of chemical synthesis, purification, analyses, and tableting to provide the desired particle size. In 1979 studies

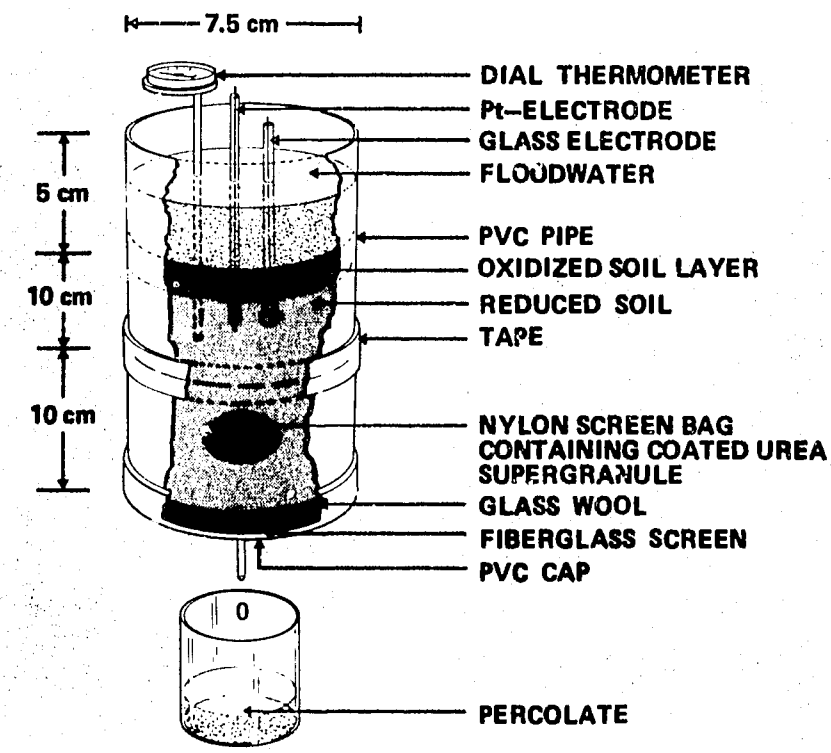


Figure 3. Schematic Diagram of a Simulated Wetland Soil System Used in Measuring Urea Release From Deep-Placed Coated Supergranules of Urea.

were made of triuret, glycoluril, and oxalyl diureide. In 1980 other materials (see Table 1) were studied. The cost of nitrogen in these materials is significantly higher than that in urea. Thus, the potential for agronomic superiority compared with that of urea is receiving first priority; if achieved, lower cost production methods must be found.

As part of the nitrogen research begun in 1979, tests were continued to prepare and agronomically evaluate selected nitrogen compounds exhibiting varying degrees of water solubility.

Urease and Nitrification Inhibitors

In 1980 IFDC began research that involved the addition of nitrification or urease inhibitors to urea. Inhibitors may present one way to improve nitrogen efficiency of urea by chemically controlling the biological processes that affect nitrogen losses and plant utilization. Inhibitors being studied were mixed with urea in varying proportions and tableted, except for neem cake and neem oil, which was coated onto urea with a binder. Depending on the material, additions of nitrification inhibitors to urea ranged from about 0.2% to 10.0%, and for urease inhibitors, they ranged from 2.0% to 5.0%. In some preparations, combinations of inhibitors were added. Neem cake and neem oil are reported to have nitrification-inhibiting properties and are of special interest to IFDC. Especially in the United States, 2-chloro-6-(trichloromethyl) pyridine (N-Serve) is being used commercially for incorporation with anhydrous ammonia or urea-ammonium nitrate solutions. These types of products will be evaluated on intermittently flooded rice and various upland crops. If the products have superior agronomic characteristics, technical and economic methods for preparation with urea appear possible. IFDC is cooperating with TVA in the study of inhibitors.

LOWLAND NITROGEN PROGRAM

Identification of Causes and Magnitude of N Losses

Losses of nitrogen are largely responsible for the poor efficiency of nitrogen fertilizers applied to lowland rice. IFDC has therefore concentrated much research on using the ^{15}N balance technique to determine the magnitude of nitrogen losses under laboratory, greenhouse, and field conditions. This research has been supported by measurements of gaseous losses as ammonia or nitrous oxide to pinpoint the loss mechanisms involved. Much of the field research on nitrogen losses is conducted at the International Rice Research Institute (IRRI) where IFDC has had a soil scientist posted since 1978.

Losses of nitrogen are largely responsible for the poor efficiency of nitrogen fertilizers applied to lowland rice.

Labeled Nitrogen Fertilizers

Numerous samples of fertilizer tagged with ^{15}N were prepared at IFDC Headquarters for agronomic study. Although urea and urea compounds made up the bulk of the samples, diammonium phosphate (DAP) and ammonium sulfate also were processed. In some cases, the labeled nitrogen source was mixed with nitrification or urease inhibitors. Tableting (2.39-3.18 mm) was the primary method used for producing a discrete particle. Certain particle sizes and quantities of tablets were prepared by TVA for nitrogen-loss studies at IFDC Headquarters and overseas.

Table 1. Nitrogen Compounds With Limited Water Solubility

Compound[a]	Nitrogen Content, %	Water Solubility[b]
Oxalyl diureide	32.2	<0.1
Glycoluril	39.6	<0.1
Isobutylidene diurea	32.2	0.1
Difurfurylidene triurea	25.0	<0.1
Poly(methylene/ethylidene) polyurea-P(M/E)PU	36.4	-
Dicyandiamide-(DCD)	66.7	3.5
Guanylurea sulfate	35.0	5.0

a. Particle-size range of powder not determined. Material was tableted for agronomic evaluation.
b. Expressed as parts per hundred parts of water.

Magnitude and Mechanisms of Nitrogen Losses From Continuously Flooded Soils

Greenhouse Research—Nitrogen losses from rice soils following fertilizer application depend on, among other factors, the form of nitrogen fertilizer used, the fertilizer management practice adopted, and the chemical and physical properties of the soil. Organic-matter content, texture, and pH are probably the major soil factors that affect the extent of nitrogen losses, but few systematic studies of the relationship between these properties and ammonia volatilization or nitrification-denitrification have been undertaken for flooded rice soils.

A greenhouse pot study was conducted at IRRI in 1980 to measure the loss of ^{15}N from a range of soils (collected from the Philippines, Thailand, and Indonesia) having different soil properties. Each flooded, puddled soil was amended with (1) ^{15}N-labeled urea; (2) ammonium sulfate, broadcast on the surface and incorporated; or (3) ^{15}N-labeled urea supergranules deep placed at 10 cm. Floodwater was analyzed for urea- and ammonium-nitrogen and pH. Soil and plant material was harvested 14 days after transplanting and at grain maturity for determination of recovery of ^{15}N. High levels of urea and/or ammonium nitrogen were found in the floodwater following broadcast and incorporation of urea and ammonium sulfate, but the nitrogen levels dropped rapidly over a period of 3 days. Higher floodwater urea- and ammonium-nitrogen levels were maintained in the more acidic soils where the floodwater pH remained lower than pH 7.0. Plant dry weight and grain yield were highest in all soils where supergranules were deep placed at 8 cm.

Field Research—Previous research at IRRI (see the IFDC *Annual Report, 1979*) has shown that the farmer's practice of applying urea to floodwater is a particularly poor fertilizer management technique. It is suspected that nitrogen fertilizer is being lost largely by ammonia volatilization although no direct field evidence is yet available to support this thesis.

Several approaches were used to study ammonia volatilization in the field. The loss can be determined using soil enclosures and a forced draft to displace volatilizing ammonia to acid traps. The rate of loss also can be measured indirectly using a short-term ^{15}N balance method after accounting for ^{15}N loss by other pathways. Alternatively, the rate of ammonia volatilization can be determined using micrometeorological methods that characterize the atmospheric environment above the field under study.

An effort has been made to evaluate the loss of ammonia using either the short-term ^{15}N balance technique or the micrometeorological approach. Using the short-term ^{15}N balance technique in conjunction with nitrapyrin, an inhibitor of nitrification and indirectly denitrification, it is possible to demonstrate substantial loss of nitrogen, presumably by ammonia volatilization, where urea and ammonium sulfate were applied to an alkaline floodwater (Table 2). The absence of any effect of nitrapyrin indicates that the loss of fertilizer via nitrification and denitrification (a traditionally accepted major pathway of nitrogen loss in flooded soils) was not important in Maahas clay during this study.

Ammonia loss, however, is not measured directly with the ^{15}N balance technique. More accurate data are obtained from studies where micrometeorological techniques are employed. The horizontal flux technique was used on a trial basis at IRRI in 1980. Difficulties with meteorological equipment and the ammonia trapping method and the general unsuitability of the land on which the studies were made resulted in incomplete and unsatisfactory data collection. Measures have been taken to overcome these difficulties.

Left—*Researchers set up isotope experiments for the IFDC/IRRI collaborative project at IRRI in the Philippines.*

Right—*Researchers establish a ^{15}N mini-network experiment at Punjab Agricultural University in India.*

Table 2. Percentage of Recovery of Nitrogen Added as Ammonium Sulfate and Urea, 100 kg Nitrogen per Hectare

Weeks After Flooding	Treatment			
	AS	AS + N	U	U + N
1	39.4	42.8	62.4	62.8
2	36.0	35.0	-	-
4	38.1	35.0	44.3	47.3

U = urea; AS = ammonium sulfate; N = nitrapyrin.

Network of ^{15}N Experiments With Rice

Research results obtained using ^{15}N in the field at IRRI require verification at a number of key representative sites in other rice-growing areas of Asia. This is being attempted through a network approach in which the same experiment is conducted at a number of sites. The objective is to determine the effect of different fertilizers on crop recovery, immobilization, and losses of nitrogen applied to lowland rice grown in a wide range of soil, water, and climatic environments. The institutions involved to date are: Indian Council of Agricultural Research; Institute of Agricultural Sciences, Korea; Department of Agriculture, Thailand; and Fujian Academy of Agricultural Science, People's Republic of China.

Research results obtained using ^{15}N in the field at IRRI require verification at a number of key representative sites in other rice-growing areas of Asia.

During 1980 as part of this international network coordinated by IFDC and IRRI, ^{15}N balance experiments were conducted in the field in India, Thailand, and Korea. The extensive laboratory work to analyze the soil, plant, and water samples from these experiments for nitrogen and ^{15}N is still in progress. In India, a residual experiment using wheat following the rice crop has been initiated.

A training course on ^{15}N techniques was held in November at IFDC Headquarters for the cooperator from the People's Republic of China. A scientist from the Hindustan Fertilizer Corporation Limited (HFC) also attended the course; he then received a further 2 weeks of intensive training on the operation of the IFDC mass spectrometer.

The immediate results from this research will flow to the International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) cooperators since the purpose of the ^{15}N network was to provide basic backup information to help explain the site-to-site variability in the INSFFER data (see INSFFER section).

Nitrous Oxide Production in Continuously Flooded Environments

Earlier field results from IRRI indicated that nitrous oxide evolution is minimal in flooded rice culture following application of fertilizer. Because nitrous oxide is one product of denitrification, it is tempting to conclude that denitrification may be minimal in flooded soils. Further studies were undertaken in 1980 on nitrous oxide production under field conditions. Loss of nitrous oxide was determined following either topdressing or broadcast and incorporation of urea or ammonium sulfate. The total loss of nitrous oxide over a period of 10 days in

the urea topdress treatment was estimated to be 0.1 kg of nitrogen per hectare. Lower rates of loss were noted from plots following broadcast of ammonium sulfate than from broadcast and incorporated urea treatments. When an allowance was made for potential nitrogen gas production (using nitrous oxide/nitrogen ratios established from studies using nitrate as a fertilizer material), it was estimated that denitrification may have accounted for the loss of 15 kg of nitrogen over the 10-day period—a significant loss.

Results from a series of soil studies showed that the rate of nitrous oxide production varied widely in different soil types. Nitrous oxide production was most significant at lower soil pHs. This relationship was not always consistent, however. Future research will be directed toward obtaining information on both nitrous oxide and nitrogen production. Methodology to achieve this is being developed.

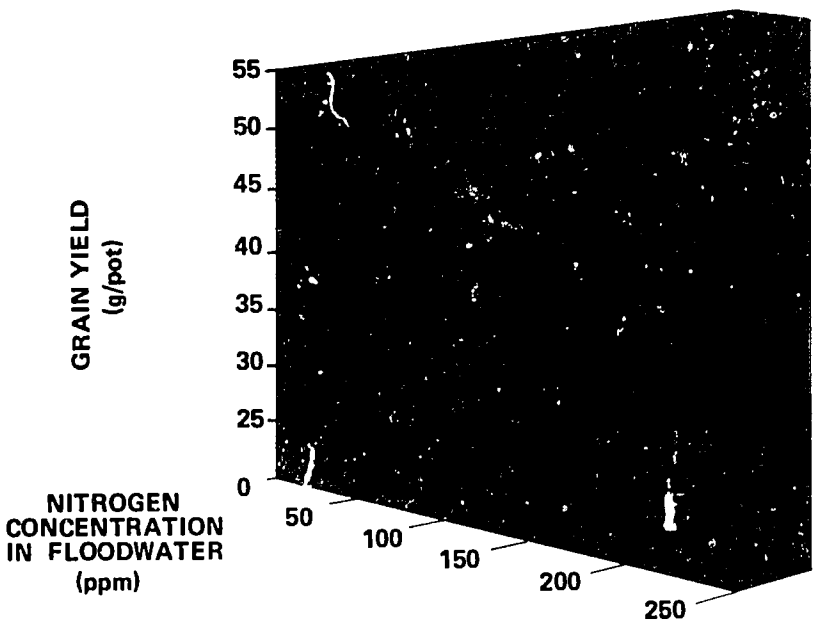


Figure 4. Relationship Between Rice Yield and Floodwater Nitrogen Concentration Produced When Urea Was Applied by Nine Different Application Methods to Wetland Rice in the Greenhouse.

Fate of Nitrogen Applied to Rainfed or Simulated Rainfed Environments

Although almost two-thirds of the rice-growing area in South and Southeast Asia is cultivated under rainfed conditions with little control over floodwater, there is little available information on the efficiency of utilization of nitrogen use under rainfed environments. IFDC research on the nitrogen fertilization of rainfed rice was therefore expanded in 1980.

Greenhouse Research—Few data are available on the effects of interactions between soil moisture, nitrogen availability, and nitrogen use by the crop.

Two greenhouse pot studies were conducted to evaluate the effect of soil moisture deficits on nitrogen use by lowland rice. Significant reductions in growth were observed at relatively low soil moisture tensions, resulting in a lowered uptake of nitrogen in stressed treatments. However, soil analyses failed to show appreciable nitrate accumulation with soil drying, contrary to widely held views. Loss of nitrogen is being evaluated by the ^{15}N balance technique.

Field Research—Fertilizer trials were conducted in collaboration with personnel from IRRI in rainfed areas in the Philippines. Conventional and modified urea materials were evaluated at four levels of application. The results generally showed little advantage in the use of nitrogen fertilizer and no advantage to the use of modified urea forms. Soil and plant material are being analyzed to determine availability and uptake of nitrogen.

Development of Products and Practices to Reduce Losses

Effect of Fertilizer Placement on Fertilizer Efficiency

Previous studies at IFDC Headquarters, IRRI, and various national research centers of developing countries proved that deep placement of urea supergranules markedly increased yield and nitrogen recovery compared with surface applying and incorporating similar quantities of nitrogen into the soil. No definitive research had been conducted to show the importance of deep placement *per se* versus deep-point placement. During 1980 a greenhouse experiment was conducted at Headquarters to determine the effects of different methods of placement of various nitrogen fertilizers on the growth response of rice and on nitrogen losses. The experiment was conducted with transplanted rice grown in puddled soil. Urea, ammonium sulfate, or SCU were applied at a point, in a band, or broadcast; fertilizers were applied on the soil surface, at a 10-cm depth after removing the surface (0-10 cm) soil layer, or at a 5-cm depth and mixed into the surface (0-5 cm) layer.

During 1980 a greenhouse experiment was conducted at Headquarters to determine the effects of different methods of placement of various nitrogen fertilizers on the growth response of rice and on nitrogen losses.

Surface application of ammonium sulfate gave higher grain yields than surface application of urea or SCU. Placement of the fertilizers at a 10-cm depth increased yields, but for this depth of application, no yield differences between point, band, or broadcast application were observed. The most striking feature of the data is that for the nine different combinations of placement depth and pattern, rice yield was inversely related to the concentration of nitrogen fertilizer in the floodwater 1 day after the different fertilizers were applied. Figure 4 shows this relationship for the urea treatments. Broadcast urea on the surface of the soil produced the highest floodwater nitrogen concentration and the lowest yield. However, even point placement of urea at a 10-cm depth produced a floodwater nitrogen concentration of 16 parts per million; this nitrogen was largely urea, which must have moved in solution during the replacement of the 0- to 10-cm saturated soil layer. The linear correlation coefficients for the yield and floodwater nitrogen data from the SCU and ammonium sulfate treatments were lower than the coefficient obtained for the urea treatments, probably because the SCU and ammonium sulfate were either less mobile than urea and/or less susceptible to ammonia volatilization than urea.

The measurement of nitrogen fertilizer in the floodwater is an invaluable aid to the interpretation of data from experiments on nitrogen fertilizer efficiency for rice and should be a particularly useful tool in research on fertilizer placement equipment for rice.

The data from this experiment support field data discussed in the *IFDC Annual Report, 1979*, which suggested that any fertilizer material or fertilizer management practice producing high concentrations of urea or ammonium in the floodwater will be inefficiently utilized by the rice crop. The measurement of nitrogen fertilizer in the floodwater is an invaluable aid to the interpretation of data from experiments on nitrogen fertilizer efficiency for rice and should be a particularly useful tool in research on fertilizer placement equipment for rice. The data also suggest that deep-point placement of supergranules may not be necessary if suitable equipment is available to place conventional urea deep in puddled soils so that none of the fertilizer dissolves in the floodwater.

Inhibition of Urease Activity in the Flooded Rice System

Considerable evidence has been gathered indicating that ammonia volatilization, occurring soon after fertilization, is the major loss mechanism of traditionally applied (broadcast and incorporated) urea. This finding has prompted research at IFDC Headquarters on chemicals to inhibit the hydrolysis of urea to ammonium in the floodwater and surface soil. Inhibition of the enzyme urease delays conditions conducive to ammonia volatilization; thus, the plant is allowed more opportunity to compete for the urea-N. Experiments were conducted to study the site of urea hydrolysis in the soil and floodwater system and determine whether hydrolysis was affected by chemicals having known urease inhibitory effects. Using ^{15}N-labeled urea, it was found that 50%-60% of broadcast and incorporated urea-N was dissolved in the floodwater following fertilization and that this urea was rapidly hydrolyzed to ammonia-ammonium species at the soil-water interface in 3-4 days. Of the three urease inhibitors tested, only phenylphosphorodiamidate (PPD), applied at a rate of 1%-2% of the urea, significantly delayed the hydrolysis of urea and the appearance of aqueous ammonia in the floodwater. This is a promising result, and further tests are planned to determine the effectiveness of PPD in reducing ammonia losses and increasing nitrogen fertilizer recovery by rice.

Considerable evidence has been gathered indicating that ammonia volatilization, occurring soon after fertilization, is the major loss mechanism of traditionally applied urea.

Evaluation of Products and Practices

Evaluation at Headquarters

The experimental fertilizer materials produced at IFDC represent the design criteria set by soil and crop scientists, chemists, and engineers. One of the first steps in the evaluation of any new nitrogen fertilizer is greenhouse testing. The two main criteria used in this evaluation are grain yield and apparent fertilizer recovery by the plant.

The experimental fertilizer materials produced at IFDC represent the design criteria set by soil and crop scientists, chemists, and engineers.

The 1980 fertilizer evaluation experiment consisted of a comparison of slow-release materials, deep-placed materials, and a combination of the two. Standard treatments included a control, which received no nitrogen; ordinary urea applied at transplanting (basal urea); and a split application of urea, 50% applied at transplanting and 50% applied at the panicle initiation stage. In all treatments, except the split urea, all of the fertilizer was applied just before transplanting and either broadcast and incorporated into the top 5 cm of the soil or, in the case of urea supergranules, placed at an 8-cm depth and 10 cm from the plant. The rice variety IR36 was transplanted to 8 kg of Crowley silt loam soil that was continuously flooded with approximately 5 cm of water.

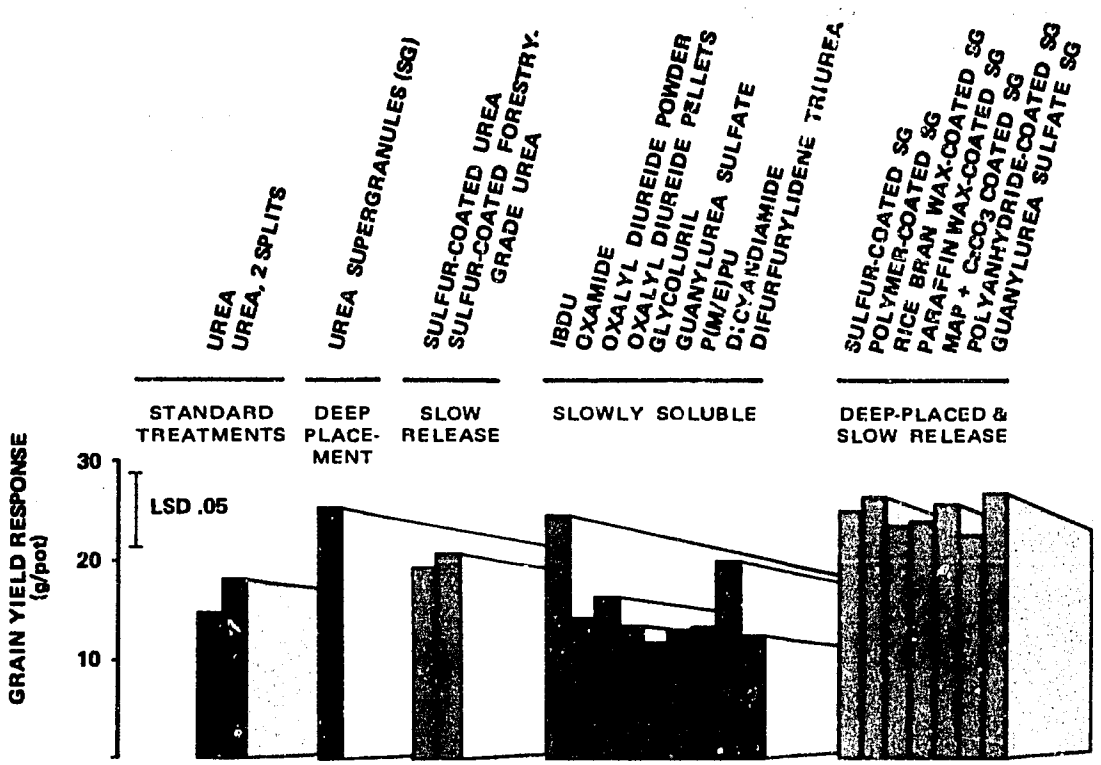


Figure 5. Results of 1980 Nitrogen Fertilizers for Rice Evaluation Experiment.

The yield response, which is the increased grain yield over the control treatment, is shown in Figure 5. Among the broadcast and incorporated slow-release materials, only isobutylidene diurea (IBDU) was superior to basal urea, while all the deep-placed supergranules, coated and uncoated, performed better than basal applications. No additional response was observed from coating supergranules. An expected benefit of coating supergranules is a reduction in leaching losses. Since no water percolation occurred in this experiment, the lack of an additional response from the coating was not unexpected. The results indicate that under greenhouse conditions the slow-release characteristics of the coated supergranules were not detrimental to crop growth.

Evaluation by the International Network on Soil Fertility and Fertilizer Evaluation for Rice

INSFFER consists of representatives from national institutions who are engaged in research to improve fertilizer efficiency on rice. This network, organized and coordinated jointly by IRRI and IFDC, has been in operation since 1975. In 1980, 54 nitrogen efficiency trials were conducted for irrigated, rainfed, and deep-water rice in 12 countries. The trials continued to show that at many locations deep-point placement of urea supergranules and broadcast and incorporated SCU gave significantly higher yields than equivalent rates of nitrogen from urea applied as best split. However, variability in response to nitrogen and in relative responses to materials among locations presents a problem in attempting to make interpretations from the data. Careful site characterization probably would permit a better understanding of agronomic data. The principal emphasis for future trials will be to obtain site characterization data to permit the analysis of responses by certain groups of sites, to enable the identification of effects of variables upon response, and to allow the data to be used for prediction of potential areas where a particular material or method of application should be used.

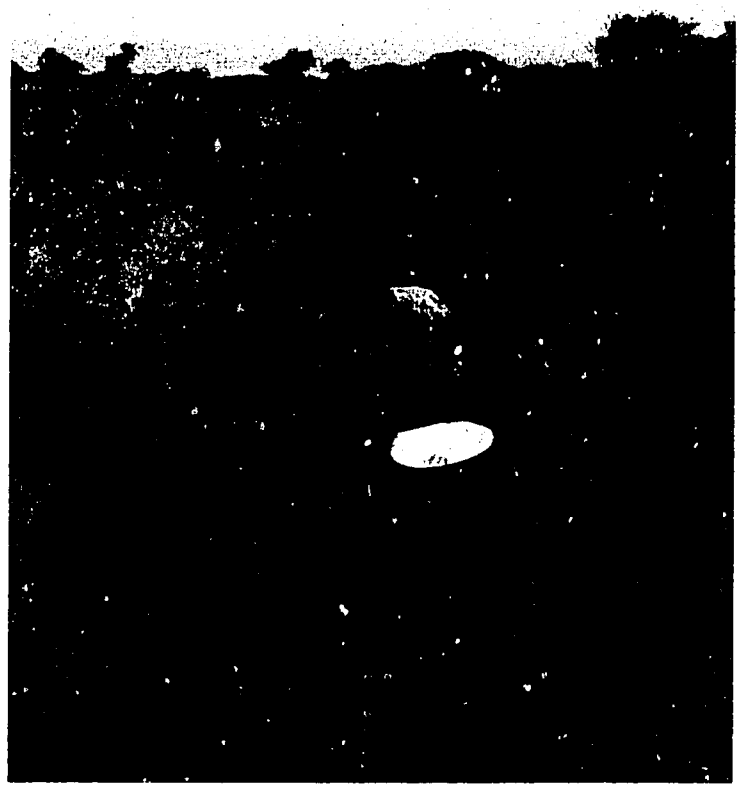
In 1980, 20 participants from 8 countries attended the 4-month INSFFER training program at IRRI. Time devoted to lectures and practical exercises (laboratory and field) was about equally divided. The training staff was principally IRRI staff, but three scientists from IFDC also participated as instructors.

Evaluation at National Institutions

Products that have been successfully tested at IFDC Headquarters and other IARCs and associated networks are then evaluated at appropriate national institutions. These tests are carried out on experiment stations and in farmers' fields. Urea supergranules have reached that stage of development.

Collaboration With Hindustan Fertilizer Corporation Limited—HFC of India is interested in determining the suitability of deep placement of nitrogen to the farmers it serves. It has been cooperating with IFDC in this effort since 1977. Comparison of deep-point placement of urea (supergranules) at the time of transplanting of rice and split broadcast application of urea (1/3 basal incorporated, 1/3 broadcast at maximum tillering, and 1/3 broadcast at panicle initiation) has been made in farmers' fields in six states in eastern India. Three replicates of zero and three positive rates of nitrogen were used in the tests. Phosphorus and potash were applied basally as single superphosphate (SSP) and potassium chloride at rates of 40 kg/ha each of phosphorus and potash.

Preliminary results from an agroeconomic analysis revealed that it took less nitrogen to achieve maximum net returns for supergranules than for broadcast prilled urea. These findings applied to all states both in the wet and dry seasons. This analysis assumed that the nitrogen cost of urea supergranules was 10% greater than that of prilled urea and that 4 days of labor was required to apply urea and 15 days for urea supergranules.



An Indian farmer applies fertilizer to his sorghum crop. Fertilizer use in the semiarid tropics of India has traditionally been small.

UPLAND NITROGEN PROGRAM

Nitrogen fertilization problems and requirements in developing countries differ with crop-growing and climatic conditions. Therefore, in establishing an upland nitrogen program, IFDC followed agroclimatic zonation. Collaboration was established with several IARCs that have mandates for specific agroclimatic zones. Priority was given to regions of the world with large food deficits.

A research program in the semiarid tropics of India was started with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). A cooperative program was also developed with the International Center for Agricultural Research in the Dry Areas (ICARDA) in the arid areas (Mediterranean winter-rainfall regions) of West Asia.

Identification of Causes and Magnitude of N Losses

In 1980 IFDC launched a major research effort to identify the problems related to nitrogen fertilizer utilization by principal food crops in the semiarid tropics, arid areas, and the humid tropics.

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Nitrogen Transformations

A high priority was given to the study of urea transformations in soil because urea is expected to remain one of the most important nitrogen sources for the foreseeable future in the developing world. Urea applied to soil breaks

down to ammonia, which under certain conditions can be lost to the atmosphere as a gas. Earlier research (reported in prior IFDC annual reports) indicated that this loss of nitrogen as ammonia from flooded rice fields can be large.

A high priority was given to the study of urea transformations in soil because urea is expected to remain one of the most important nitrogen sources for the foreseeable future in the developing world.

Laboratory research at IFDC examined the breakdown of urea in a number of soils frequently found in the semiarid tropics. Figure 6 shows the effect of soil moisture on the rate of urea breakdown. Urea breakdown was much faster in wet than in dry soil; it was extremely low at soil-moisture contents below which plants can survive. The rate

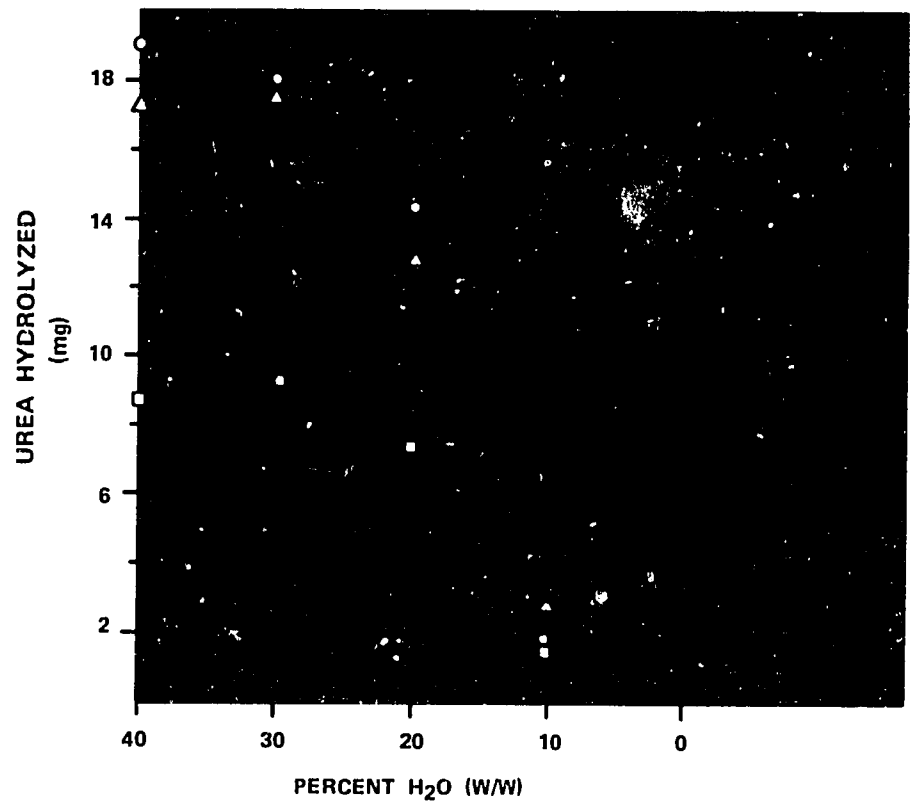
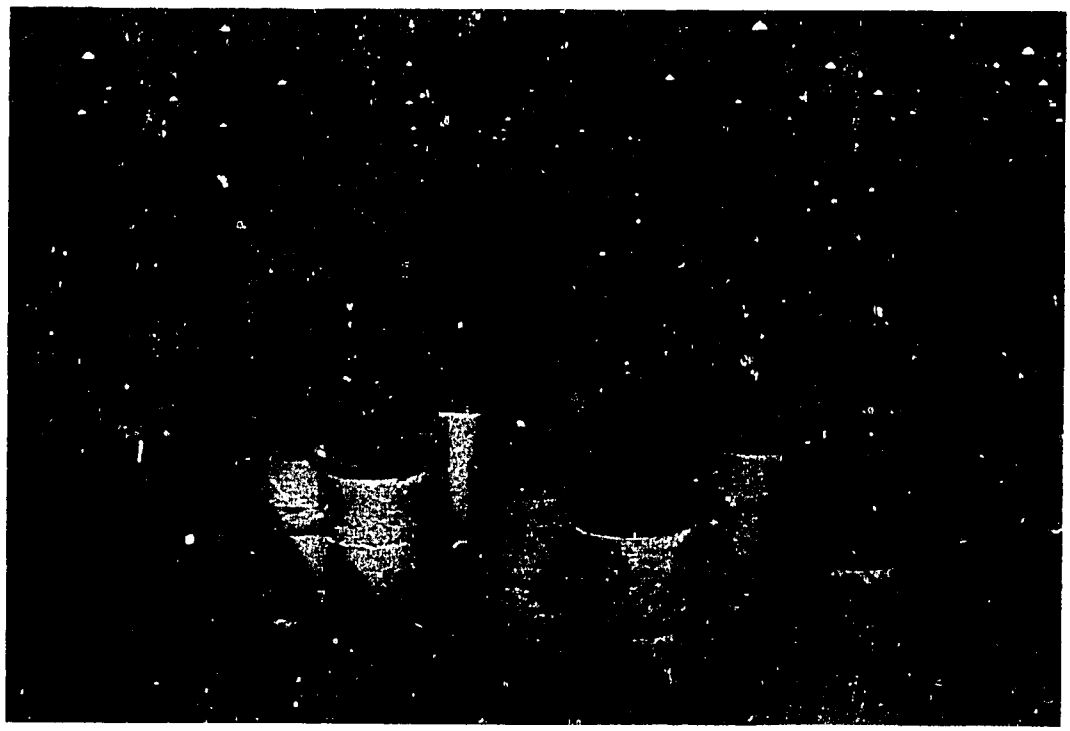


Figure 6. Effect of Soil Moisture Content on the Urease Activity of Three Calcareous Soils and One Acid Soil.



An experiment was conducted with wheat in the IFDC Greenhouse to study fertilizer efficiency as affected by soil moisture. This experiment featured deep greenhouse pots.

of urea breakdown was dependent on soil temperature; it increased with increasing soil temperature. The research findings may be helpful in determining the timing and method of urea application to prevent ammonia loss from soils in arid and semiarid tropical regions.

Fate and Efficiency of Nitrogen Sources

Studies were conducted in the IFDC Greenhouse to determine (1) the magnitude of nitrogen fertilizer loss and (2) the fraction of the nitrogen fertilizer utilized by the crop. Experiments simulated different agroclimatic conditions. One experiment was conducted with wheat grown under simulated Mediterranean, winter-rainfall (arid) conditions; another was carried out on maize grown under simulated humid tropical conditions. The experiments were carried out with U.S. soils similar to the major soils in arid and humid tropical areas. The soils were subjected to several different moisture and simulated rainfall regimes characteristic of arid and humid areas.

In the wheat experiment, the fraction of the nitrogen fertilizer taken up by the crop ranged from 15% to 56% and increased dramatically with increasing soil moisture and rainfall. Most of the remaining fertilizer not taken up by the wheat remained in the soil. The total recovery of nitrogen fertilizer in the wheat and soil is shown in Figure 7. On the average, less than 20% of the nitrogen fertilizer was not recovered. The unrecovered fertilizer presumably was lost as ammonia and other nitrogen gases during the growing season. The losses averaged 20% for urea and 14% for ammonium nitrate.

Nitrogen fertilizer may be prone to leaching losses in the humid tropics. The greenhouse experiment with maize revealed that leaching losses of nitrogen are influenced by solar radiation (sunlight). Leaching was greatest under cloudy, overcast conditions when evaporation was reduced. Such conditions are common during the rainy season in the humid tropics. Proper timing of fertilizer applications to meet but not exceed the nitrogen requirements of the crop may be an effective way to reduce leaching loss.

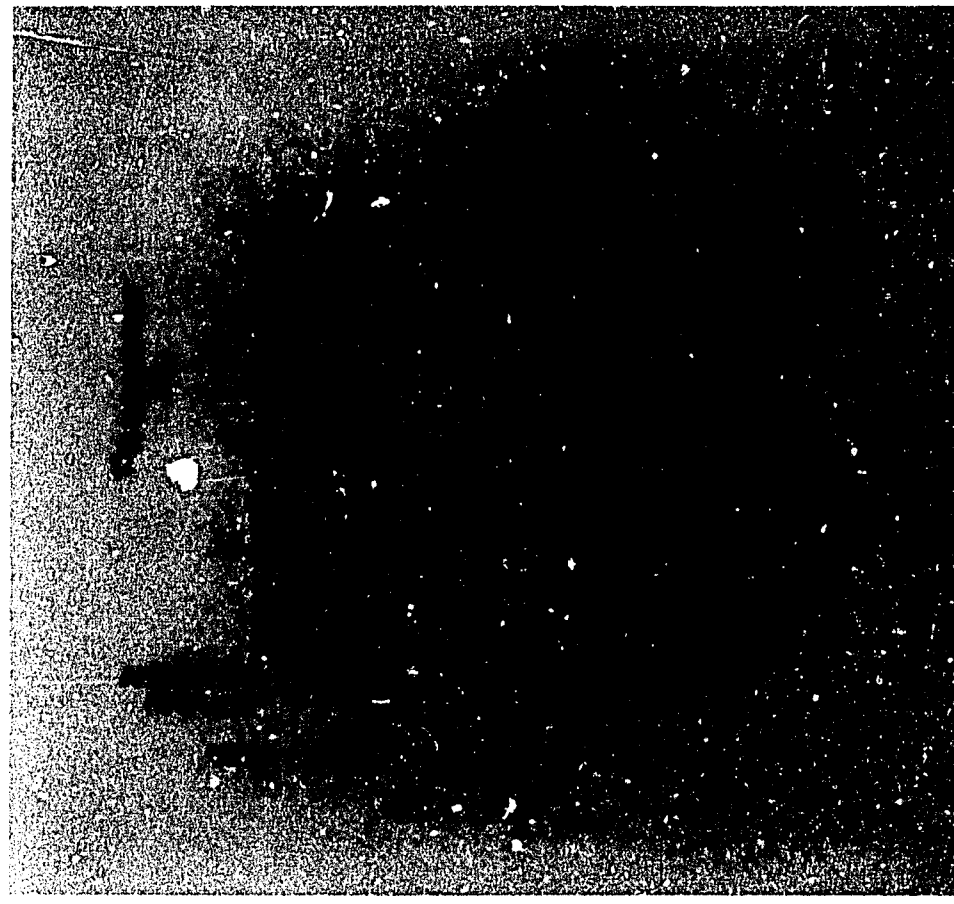


Figure 7. The Influence of Nitrogen Source and Available Soil Water on the Uptake of Fertilizer Nitrogen by Wheat and the Total Recovery of Fertilizer Nitrogen in the Wheat and Soil.

Evaluation of Products and Practices

Most upland soils contain microorganisms that convert urea and ammoniacal nitrogen to the nitrate form. While nitrogen in this form is readily available to most crops, it can under certain conditions be lost through leaching or denitrification. There are chemical compounds, called inhibitors, which prevent or slow this conversion from ammonium N to nitrate nitrogen.

A greenhouse experiment with maize evaluated the use of nitrification inhibitors under humid tropical conditions.

Evaluation at Headquarters

A greenhouse experiment with maize evaluated the use of nitrification inhibitors under humid tropical conditions. Nitrification inhibitors are known to improve the utilization of nitrogen fertilizers by reducing leaching and denitrification (gaseous) losses. The amendment of either ammonium sulfate or urea with N-Serve (a commercially

available nitrification inhibitor) did not increase yield or nitrogen fertilizer uptake by maize. The ineffectiveness of the inhibitor was due to (1) low denitrification and (2) high soil temperatures, which decrease the inhibitor's effectiveness.

Evaluation at Other International Centers

IFDC/ICRISAT Collaboration—Since May 1980 an IFDC soil scientist has been conducting fertilizer studies with scientists at ICRISAT in India. Field experiments were established on a sandy, red soil (an Alfisol) and a black, cracking clay (a Vertisol) during the 1980 rainy (summer) season. Sorghum, a major food crop in the semiarid tropics, was grown in the experiments.

Sorghum responded to nitrogen fertilizer on both soils. Grain yields in the Alfisol experiment are shown in Figure 8. The amendment of urea with the nitrification inhibitor dicyandiamide (DCD) did not increase yield. The utilization of urea fertilizer by sorghum was greater when urea was banded at 2 and 4 weeks after planting than when it was all applied on the soil surface or incorporated into the soil at planting. Approximate recoveries of nitrogen fertilizer by sorghum for banded urea, surface-applied urea, and incorporated urea were 67%, 54%, and 54%, respectively.

IFDC/ICARDA Collaboration—In April 1980 IFDC and ICARDA entered into an agreement to conduct cooperative research on fertilizers in dryland farming in Mediterranean, winter-rainfall regions. Two field experiments were initiated in late 1980 at ICARDA research sites in Syria. The ^{15}N-labeled fertilizers for the experiments were supplied by IFDC. Results from this work will be reported in 1981.

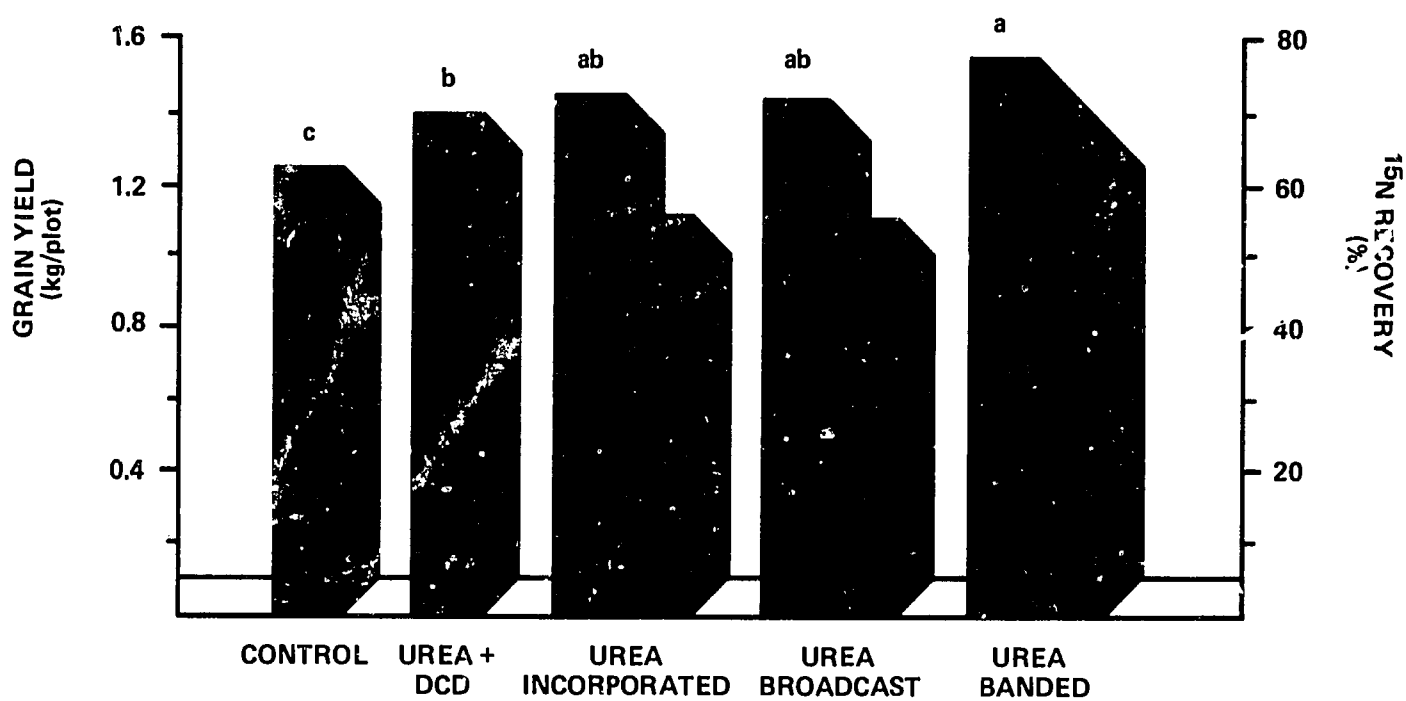


Figure 8. Influence of Nitrogen Source and Placement on Grain Yield for Sorghum Grown on an Alfisol at ICRISAT. Fertilizer N Uptake Data are Included for the Treatments That Received ^{15}N.

Note: Data represented by bars labeled with different letters (a, b, c) are significantly different (Duncan's multiple range test).

SUMMARY AND FUTURE WORK

The IFDC Nitrogen Research Program has shown that no single product or management system is likely to achieve the desired improvement in nitrogen use efficiency for the variety of soils and crops encountered in developing countries. Instead a family of nitrogen products is likely to emerge with each suited to improve nitrogen recovery and yield for a given set of physical and economic conditions. The research is at a stage where more in-depth evaluation on fewer products is needed.

. . . a family of nitrogen products is likely to emerge with each suited to improve nitrogen recovery and yield for a given set of physical and economic conditions.

A key to future work is the urea substrate that is likely to be available commercially to facilitate deep placement. Granular urea particles larger than normal-sized prills (1.6 mm) are becoming available in developing countries. Larger particles are favored because of superior handling properties and for coating of urea because less coating is required for a desired nutrient release rate. IFDC intends to fully explore the potential for coating, emphasizing the use of indigenous materials. Some additional work on the screening of organic forms of nitrogen will be done. As indicated previously, inhibitors for urea offer promise and will be evaluated in depth. IFDC will continue to provide a wide range of experimental products, primarily in small quantities, for evaluation by soil scientists and agronomists in developing countries who are working in collaborative projects with IFDC. Products with potential will then be evaluated at the process development stage involving larger scale production and economic studies. As work on upland crop systems expands, there will be a demand for various additional study materials, especially ammonium nitrate-based fertilizers.

Granular urea particles larger than normal-sized prills (1.6 mm) are becoming available in developing countries. Larger particles are favored because of superior handling properties and for coating of urea because less coating is required for a desired nutrient release rate.

Phosphate Research

Phosphate rock is the basic ingredient for production of phosphate fertilizers. As a raw material it has the inherent characteristic of varying widely in physical/chemical composition, quality, texture, and reactivity. It is usually found in deposits of varying degrees of concentration and size in a large number of countries including many developing countries. Only a few of these deposits have been developed commercially with the most notable being those in the United States, U.S.S.R., Morocco, and Tunisia. The steady rise in the cost of phosphate rock concentrate and skyrocketing price of sulfur, a basic ingredient used in the manufacture of most finished phosphates, have caused developing countries to look for alternative and cheaper ways to furnish phosphate fertilizer to their farmers.

IFDC's phosphate research program is aimed at helping developing countries to look for ways in which they may (1) develop their own phosphate deposits and (2) reduce the costs of producing phosphate fertilizers by looking at less energy- and capital-intensive technology. The phosphate program deals with (1) characterization of ores from phosphate rock deposits, (2) beneficiation of phosphate ores to produce phosphate concentrates, and (3) development of ways to utilize the phosphate rock concentrate directly as a fertilizer or through some chemical modification to enhance its suitability as a phosphate source for crops. In order to accomplish this, phosphate materials are subjected to a number of tests in the laboratory, pilot plants, and greenhouse, and the resultant products are evaluated at various agricultural research centers around the world. By so doing, IFDC can identify the chemical, physical, and economic properties that will lead to the effective use of the end products in developing countries. This research effort is focused at specific agricultural centers for intensive evaluation and into special projects when a particular ore is being evaluated.

During 1980 IFDC prepared experimental products from a wide range of ore types from developing countries, with emphasis on reducing the energy and raw material costs for production. Intermediates and products such as rock concentrates from beneficiation, wet-process phosphoric acid, granulated rock, partially acidulated and granulated rock, and granulated NP and NPK products were studied.

PHOSPHATE ORE CHARACTERIZATION

Efforts continued to classify information on phosphate ores throughout the world according to size and quality of deposits, economic and technical potential for development, and identification of further work required for a deposit's exploitation. Technical data of a given ore are derived through a systematic study of chemical and mineralogical composition, texture, reactivity, and grindability characteristics called characterization. This information is essential in planning a strategy to utilize a particular deposit.

Efforts continued to classify information on phosphate ores throughout the world according to size and quality of deposits, economic and technical potential for development, and identification of further work required for a deposit's exploitation.

Activities in this area in 1980 concentrated on Africa and included exchanges from India and Sri Lanka with receipt of 22 samples from 14 countries.

BENEFICIATION TO PRODUCE CONCENTRATES

Most phosphate ores are not sufficiently concentrated in their natural state to allow their direct use in the production of phosphate fertilizers. Some concentration of the ore is required. The techniques used will vary with the type and quality of the original ore.

IFDC/TVA Cooperative Project

During the past 4 years, TVA has been evaluating new phosphate-collecting agents in bench-scale beneficiation tests. Their tests identified four new reagents that appear to have greater selectivity than the industrial tall oils now used by the phosphate industry. In a cooperative project, a series of continuous pilot-scale tests were conducted to obtain data on the performance of these new collectors. The three ores selected were low in grade and contained silica and carbonate impurities. Tests were made to study the effects of ore grade and particle size on selectivity of the proposed reagents. A commercial tall oil of the type used in conventional processes was included as the control reagent. The identification of alternative sources of flotation reagents might enable developing countries to produce these reagents from indigenous sources of waxes, fats, and oils. In addition, the development of improved reagents would conserve natural resources and improve the economics of benefici-

ating a low-grade deposit in a developing country. Furthermore, these beneficiation studies may identify simplified technology that might be applicable where conventional technology is not. This is a major technological problem for phosphate ores throughout the world.

Pilot-Plant Improvements

IFDC conducted additional studies on phosphate rock beneficiation to confirm the procedures developed during 1979 and to improve pilot-plant operations. Modification of the conditioning circuit included new tanks, new outlets on the old tanks, and improved agitation. In the flotation circuit, agitation was increased, baffles between the cells were removed, and improvements were made to the cell discharge and level controls. Two individual cleaner cells were built and tested. These improvements greatly increased the mechanical reliability of parts of the beneficiation pilot plant. Subsequent testing has shown that modified plant units operate well and produce reliable results after steady-state operation has been achieved about 1-2 hours after startup. Further tests are planned to confirm the suitability of the plant for beneficiation of problem ores from developing countries.

FERTILIZERS BASED ON PHOSPHATE ROCK

Granulated Urea and Phosphate Rock

IFDC continued study of the preparation of cogranulated urea and finely ground phosphate rock in pilot-plant scale. A cogranulated product containing P_2O_5 from phosphate rock and nitrogen from urea is a potentially economical NP fertilizer for developing countries. Three phosphate rocks were used at several $N:P_2O_5$ ratios to determine (1) the technical feasibility of cogranulating urea and phosphate rock, (2) the maximum proportion of phosphate rock that can be used (minimum $N:P_2O_5$ ratio), (3) the drying requirements of the product, and (4) the phosphate recovery and the comparative suitability of phosphate rocks for cogranulation.

A cogranulated product containing P_2O_5 from phosphate rock and nitrogen from urea is a potentially economical NP fertilizer for developing countries.

A 1.36-m diameter pan granulator was used for granulation. Unconditioned urea prills were melted without the addition of water in a tank equipped with steam coils and then sprayed onto the rolling bed of granules in the pan granulator. Formaldehyde solution (37% concentration in water) was added as a conditioner to the urea before spraying to give a final dry-basis formaldehyde concentration of 0.4% in the urea. No attempt was made to minimize biuret formation in the urea. Finely ground (45% minus 200-mesh, Tyler) phosphate rock containing 30%-32% P_2O_5 was added continuously with a variable-speed screw conveyor. The raw rock was mixed with the recycled phosphate, which consisted of the fines and crushed oversize from the screening process before it was granulated. After granulation the granules passed through a cooler (no dryer required) and were then screened on a double-deck, vibrating, inclined screen. The product-size fraction was minus 4.7- plus 1.4-mm (minus 4- plus 12-mesh, Tyler). Dust collected from the cooler and from the fugitive dust system was not returned to the granulator. In cases of low $N:P_2O_5$ ratios, excess phosphate rock fed to the granulator decreased the liquid phase. Some water was added; thus, drying was necessary. Typical grades produced were approximately 18-18-0, 12-24-0, and 8-24-0 expressed as weight percent of N, P_2O_5, and K_2O, respectively.

No differences in operation were observed because of use of the three phosphate rocks. The products generally contained an excessive amount of nitrogen, indicating that some phosphate rock was lost as ungranulated dust. The dust was collected, but it could not be returned to the system at the same rate at which it was produced.

Granulated Phosphate Rock

Highly reactive phosphate rock as a direct application fertilizer for acid soils of the tropics is attractive for several reasons. Capital and operating requirements are relatively small, and technology is simple. Direct application of phosphate rock has been controversial because of the unpredictable agronomic value of the rock. Much of this controversy stems from a lack of understanding that phosphate rocks differ widely in their reactivity or suitability for direct application. In certain acid tropical soils highly reactive, finely ground phosphate rock can be almost as agronomically effective as soluble phosphate fertilizers, especially if residual crop response is considered.

One of the main objections to finely ground phosphate rock fertilizer is the dustiness associated with handling, storage, and application. Since it is water insoluble, fine grinding is considered essential to ensure high phosphate availability to the crop. Granulation is one way to improve the physical properties of ground phosphate rock. However, research has shown that the agronomic effectiveness of granulated ground phosphate rock is likely to decrease as the particle size increases at least for initial crop response. A particle-size range of minus 6- plus 14-mesh, Tyler (1.2-3.3 mm) is the common size for granular fertilizer but may not be optimum for granulated phosphate rock. IFDC continued to study a minigranulation process to produce relatively small rock granules having a size range of minus 48- plus 150-mesh, Tyler (0.1-0.3 mm). Compared with the original finely ground rock, dustiness is significantly reduced.

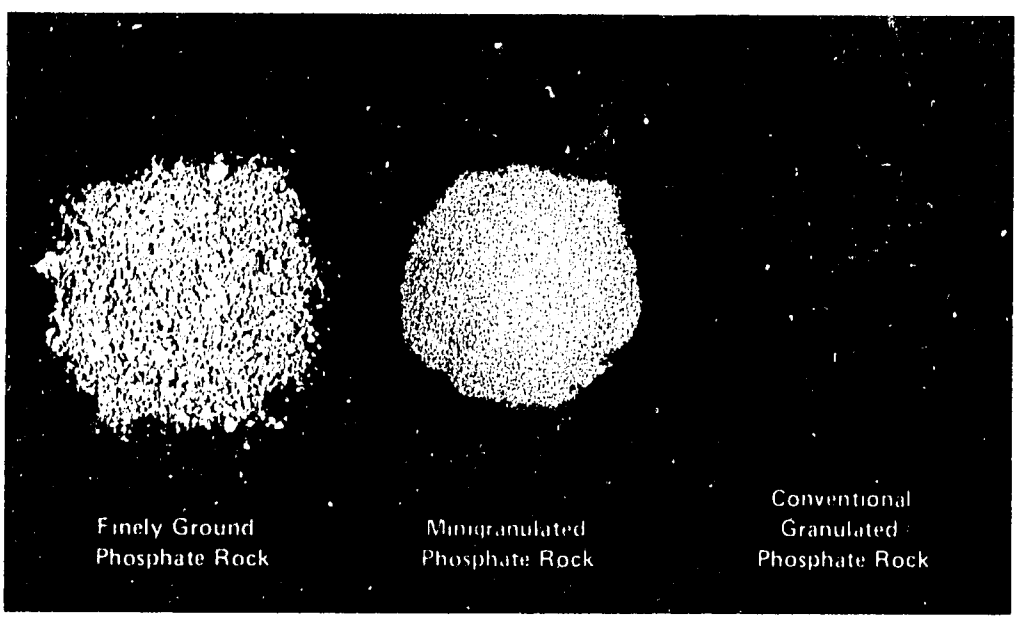
In certain acid tropical soils highly reactive, finely ground phosphate rock can be almost as agronomically effective as soluble phosphate fertilizers, especially if residual crop response is considered.

A special type of granulator called a pinmixer is used to produce the minigranules. IFDC carried out a number of pilot-plant tests to define the operating parameters of the minigranulation process when using potassium chloride as a binder. The binder is added to impact strength to the granules. The percentage of the onsize product fraction increased, and the disintegration time of the granules in water decreased when cocurrent drying was used as compared with countercurrent drying. The only advantage of using countercurrent drying was a slight decrease in degradation (relative dustiness) of the product under simulated handling and transportation conditions. However, the percentages of degradation under the cocurrent drying mode were well within the acceptable limits for granular fertilizers. Within the limit of binder concentration studied (1% and 3% in product), an increase in concentration decreased the product degradation without adversely affecting either the onsize (0.1-0.3 mm) fraction or the disintegration time.

Wet-Process Phosphoric Acid

Phosphoric acid is an important intermediate, which is used for producing ammonium phosphates and triple superphosphate (TSP). Tests were made in laboratory (bench-scale) and pilot-scale equipment to obtain data for correlation with industrial-scale operation. Commercially available rocks are used in baseline tests, and results are compared with unknown rocks. Special attention is given to problems associated with scale-up such as:

1. Heat and material balances related to differences in surface: volume ratios in large- and small-scale equipment;
2. Fluorine and phosphate balances, related to the difficulty in simulating the recycling of pond water as in industrial plants;
3. Degree of agitation, which affects both rock dissolution and gypsum crystallization;



Left—*Phosphate rock-based fertilizers of various sizes and treatments are being agronomically evaluated. These include finely ground phosphate rock, minigranulated phosphate rock, and conventional granulated phosphate rock.*

Upper Right—*The quality of wet-process phosphoric acid made in the bench-scale unit depends on the quality of the phosphate rock.*

Lower Right—*Phosphate rocks are characterized in this bench-scale unit prior to being tested in the IFDC Pilot Plant.*

4. Long-term effects of continued plant operation, such as the tendency for scale to form in filters and evaporators; and
5. Predictability of corrosion/erosion characteristics of materials of construction.

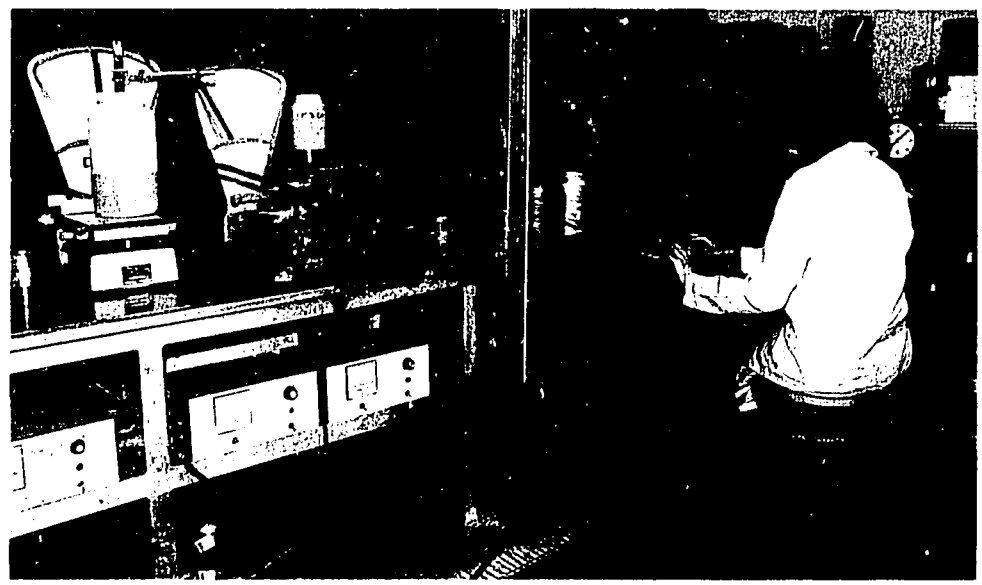
Wet-process phosphoric acid was made in the bench-scale unit and in the pilot plant. Both units had the same process flow—a single-tank digestor followed by a filter-feed tank. A batch filter was used to simulate either a tilting-pan filter or a horizontal-belt filter. The bench-scale reactor had a volume of 8 liters, and the pilot-plant reactor had a volume of 200 liters. The plants were operated in the dihydrate mode without temperature differentials across the reactor. A normal run had two periods—a transition period and the data collection period. In the transition period impurities built up in the system, and chemical equilibrium was established. Crystallization equilibrium usually lagged behind chemical equilibrium. In a run of 5 hours' retention time, a period of 30 hours for the transition and 60 hours for the run is allowed. The run period provides two types of information: (1) plant design data (or instantaneous capacities), such as reactor and filter sizes and (2) operation characteristics such as stability of the process, process upset and recovery relations, corrosion, and scaling characteristics.

A comparison of baseline test data from IFDC's laboratory- and pilot plant-scale wet-process phosphoric acid units indicated that they are adequate models of an industrial plant, and the results obtained from all units are consistent with each other. Moreover, it was demonstrated that the degree of agitation can be controlled to simulate different industrial systems. The results obtained in these studies can be used as comparative scale-up data in future tests with phosphate rocks for which no commercial experience exists. This type of work is expected to increase as more developing countries look to wet-process phosphoric acid as an intermediate for fertilizer production.

Study of a Nonaqueous Method for Titration of Sulfuric Acid in the Wet-Process Phosphoric Acid System

In the wet-process phosphoric acid system, phosphate rock is digested in sulfuric acid to produce phosphoric acid. The level of unreacted sulfuric acid in the product acid is an important process control parameter. Generally, a slight excess of sulfuric acid is needed to ensure complete conversion of the phosphate rock to phosphoric acid and to ensure stability in the steady-state system. Therefore, the product acid is analyzed for sulfuric acid at frequent intervals. Several methods are suitable for routine sulfate analysis, but only a few measure sulfuric acid directly. One such procedure investigated by IFDC during 1980 was titration in a nonaqueous solvent system.

The IFDC procedure used piperidine as a titrant and n-butyl alcohol as the



solvent. In n-butyl alcohol, the monobasic and dibasic sulfate species can be titrated separately. The first sulfuric acid proton is much more acidic than phosphoric acid, and its titration inflection point can be determined even in concentrated phosphoric acid solutions. The nonaqueous titration procedure has generally been quite reliable. However, some analytical discrepancies prompted an investigation into causes of interferences.

The five most common cations—aluminum, iron, potassium, magnesium, and sodium—were considered the most likely to cause interferences. The concentration levels of these cations in phosphoric acid were used as factors in statistically designed experiments. Results of these experiments show significant interferences from iron, aluminum, and magnesium and small effects from potassium and sodium. In addition, a buffer effect caused by free phosphate was observed.

These effects are two and three times the molar concentrations of the cations involved. A relatively small concentration of aluminum, iron, or magnesium will cause a significant error in the determination of sulfuric acid in phosphoric acid by this method. However, if the impurity levels remain constant or maintain a constant relationship to sulfuric acid, an empirical calibration will allow correction for these effects. Periodic recalibration will be necessary if the phosphate rock used has a variable composition.

The effects of sodium and potassium are small and seldom should be of significance in routine work. However, the effects do exist and were verified in a separate experiment at very high concentrations.

The major conclusion of this IFDC study is that the nonaqueous titration method for determining sulfuric acid in phosphoric acid must be empirically calibrated for each change in phosphate rock. In addition, crosschecks should be made using some other method of analysis. With sufficient care, the method is suitable for use in process control.

PHOSPHATE REACTIONS IN SOILS

Laboratory studies were carried out to study phosphate reactions in soils and factors affecting these reactions. These data are helpful in predicting the agronomic performance of selected materials. This type of research began in 1976 and is a continuing project. It is especially supportive to the agronomic research program being carried out in Latin America. Some results are discussed.

Increasing temperature is known to enhance the rates of phosphate sorption and desorption in soils. Apart from the biological effect, the net effect of temperature on phosphate availability depends on the relative degree to which the processes of sorption and desorption change with temperature after phosphate fertilizer has been applied. IFDC conducted a literature search that revealed little information on the simultaneous temperature effect on phosphate sorption and desorption. This effect could be important when the agronomic effectiveness of phosphate fertilizer in tropical soils is compared with that in temperate soils. IFDC conducted preliminary tests in two acid soils to collect data on this effect.

The tests showed that phosphate sorption increased as temperature increased. Phosphate desorption decreased with increasing temperature when sorption and desorption were carried out at the same temperatures. When desorption followed sorption at a constant temperature (25°C), the amounts of phosphate desorbed increased with increasing temperature. It appears that the sorption process is an overriding factor in the desorption process when sorption temperature is higher than desorption temperature. This suggests that, in addition to soil mineralogy, high temperature also may be the cause of the high phosphate-fixing capacity of some tropical acid soils. The temperature effect on phosphate sorption also should be considered when using phosphate desorption isotherms for evaluating phosphate fertilizer requirements of crops grown at different temperature regimes.

Increasing temperature is known to enhance the rates of phosphate sorption and desorption in soils.

The tests also revealed that temperature changes had no significant effect on the water-soluble phosphate levels in the soil treated with phosphate rock; whereas, increased temperature had a tremendous effect on reducing the water-soluble phosphate levels in the soil treated with TSP. This may be an important implication for the comparison of the agronomic effectiveness of phosphate rock and water-soluble phosphate fertilizers in the tropics. In the tropical soils with low-organic phosphate, relatively high temperature has been shown to enhance the fixation of water-soluble phosphate and to reduce its agronomic effectiveness.

Previous work at IFDC has shown that the addition of small amounts (1%-5%) of pyrophosphate to monocalcium phosphate may inhibit the formation of dicalcium phosphate dihydrate in calcareous soils and, hence, enhance the phosphate fertilizer efficiency. IFDC conducted a study in 1980 to examine the inhibiting effect of pyrophosphate on the sorption of orthophosphate by calcium carbonate and on four calcareous soils from Egypt. The effect depended on: (1) the concentration of calcium carbonate, (2) the concentration and source of the pyrophosphate, and (3) the reaction time. The study indicated that the effect increased as phosphate ratio of pyrophosphate-orthophosphate mixture increased from 1:100 to 1:25.

In experiments in agitated flasks, pyrophosphate did not inhibit the crystal growth in dicalcium phosphate dihydrate when calcium carbonate was present. The pyrophosphate seemed to react with the calcium carbonate surface to cause some kind of inhibition which temporarily retarded the sorption of the orthophosphate. In the soil incubation experiments, the dicalcium phosphate dihydrate crystals that formed in the presence of pyrophosphate were much smaller than those formed in the absence of pyrophosphate, as observed by the scanning electron microscope. These small crystals may have caused more water-soluble phosphate to be extracted from soils treated with pyrophosphate than from those without it. An agronomic study is being conducted in Egypt to evaluate this effect on crop response.

IFDC/CIAT COLLABORATION

Since 1977 IFDC and the International Center of Tropical Agriculture (CIAT) have carried out a cooperative project to identify more effective sources of phosphate fertilizer for use on the acid, infertile soils of tropical and subtropical Latin America using, where possible, phosphate sources indigenous to the region. The research strategy is based on interrelationships between (1) the chemical properties of the soils in the region, (2) the abundance of indigenous phosphate ores in the region, (3) the phosphate requirements of major crop species, and (4) the effect of crop and fertilizer management. The general hypothesis under investigation is that finely ground indigenous phosphate rock or other relatively low-cost products derived from these rocks can be economically efficient alternatives to conventional soluble fertilizer on the large areas of soils characterized by extreme phosphate deficiency, extreme acidity, high aluminum saturation, and relatively high phosphate-retention capacity.

Materials and/or practices presently showing promise include (1) direct application of the more reactive types of finely ground rock, (2) partially acidulated phosphate rock (the quantity of acid used is less than that required for superphosphate), (3) extended superphosphate (a mixture of superphosphate and finely ground phosphate rock), and (4) a minigranulated form of the more reactive phosphate rocks.

Direct Application of Finely Ground Rock

The initial effectiveness of finely ground phosphate rock is strongly influenced by the chemical solubility or "reactivity" of the apatite component of the rock. Previous reports described initial agronomic potential for a total of 12 different rock sources from Latin America as well as for six other well-characterized sources included as standards (see *IFDC Annual Report, 1979*). During 1980 samples from two additional sites from Latin America were included in greenhouse evaluations. They represent deposits located in Bolivia (Valle del Sacta) and in Colombia (Tolima).

These results show that the sample from Tolima was equally as effective as the TSP and Fosbayovar (Peru) phosphate rock samples under these conditions; the samples from Bolivia were less effective during this short cropping period.

Experiments conducted in the field, however, have demonstrated that the effect on yield of the phosphate rock's solubility diminishes with time. For example, Figures 9 and 10 illustrate

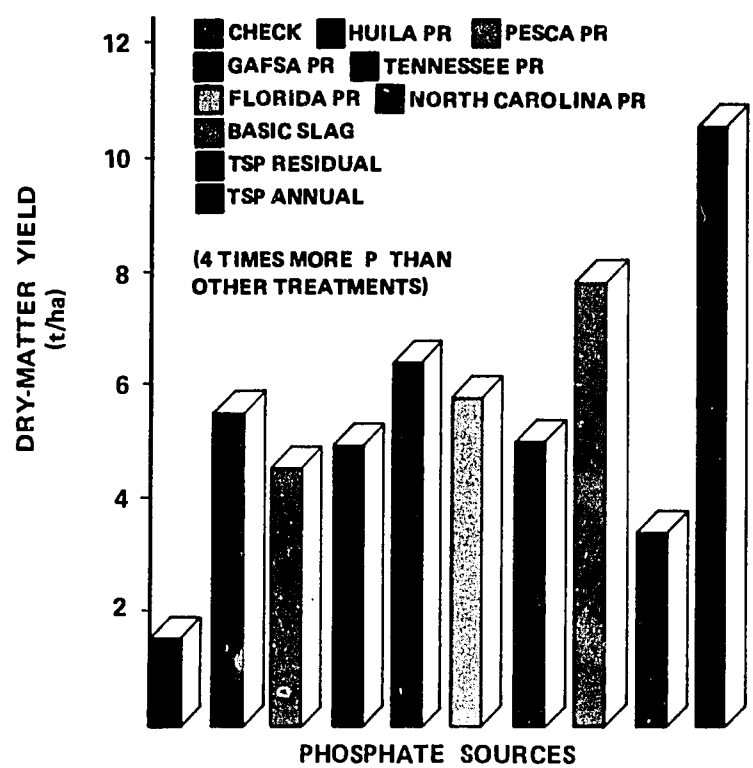


Figure 9. Dry-Matter Production From the 15th Cutting (Following 4½ Years) of *Brachiaria decumbens* as Influenced by Phosphate Source on the Carimagua Oxisol. Mean of Four Rates of Application.

results from an experiment with *Brachiaria decumbens* established in the field on the Carimagua Oxisol in 1976 and maintained to study residual value. In Figure 9, the average response of *Brachiaria decumbens* to each of 10 treatments is shown as measured in the 15th cutting following establishment of the experiment. It can be observed that the highest yield was obtained with annual applications of TSP, but among the residual treatments, TSP was the least effective and basic slag was the most effective. Among the six sources of finely ground phosphate rocks, all were essentially equal in effectiveness despite the differences in citrate-soluble phosphate; this was strongly reflected in the yields only during the first year of establishment. Even during this 15th cutting, the average yield from all phosphate rock sources was 3.4 times higher than that from the check and 1.6 times higher than the residual effect of a single application of TSP.

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During 1980 samples from two additional sites from Latin America were included in greenhouse evaluations. They represent deposits located in Bolivia (Valle del Sacta) and in Colombia (Tolima).

The accumulative production of *Brachiaria decumbens* during the 4-year period as related to phosphate source and rate of application is illustrated in Figure 10. It can be seen that response to phosphate was reflected at each increase in rate of application and that, again, there is little difference between sources. The effect of phosphate from either low, medium, or high reactivity phosphate rock has, in general, equaled or surpassed the effect from TSP at all rates of application during this time period.

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To develop a comprehensive guide to selection of source-soil-crop-management combinations on which finely ground phosphate rock presents an effective alternative to the higher cost soluble phosphates, data are being collected from a series of interrelated experiments within Colombia, Peru, and Ecuador. Collaborators in this effort include (1) Universidad Nacional Agraria, La Molina, Lima, Peru; (2) Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA), Pucallpa, Peru; (3) Yurimaguas Experimental Station, Yurimaguas, Peru; (4) Instituto Nacional de Investigaciones Agropecuarias (INIAP), Santa Catalina,

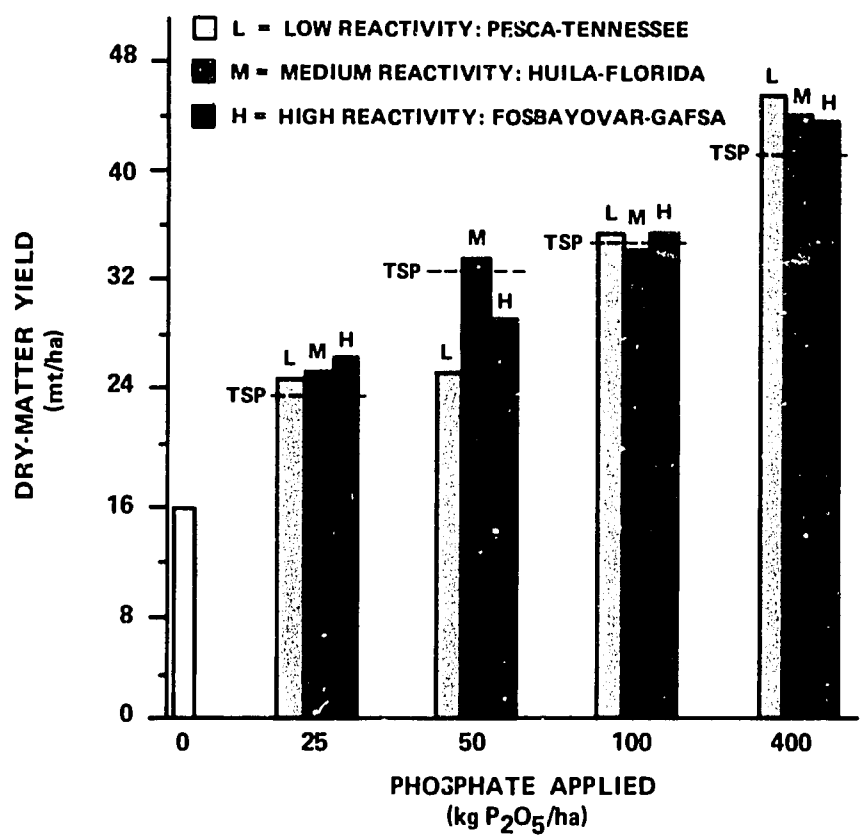

Figure 10. Accumulative Production of *Brachiaria decumbens* During 15 Cuttings (4½ Years) as Related to Phosphate Source and Rate of Application on the Carimagua Oxisol.

Ecuador; and (5) Instituto Colombiano Agropecuario (ICA), Villavicencio, Colombia.

Partial Acidulation of Phosphate Rock

It has already been shown that the immediate availability of phosphate from phosphate rocks, especially those with low or medium reactivity, may be too low for acceptable response with certain crop-soil combinations and that the overall effectiveness can only be determined by including residual value. In those situations where immediate availability of phosphate is required, however, it is possible to produce increased amounts of water-soluble and available phosphate by treating the rock with acid such as sulfuric or phosphoric. Partial acidulation is a means of accomplishing this while consuming only a portion of the acid required for superphosphate and leaving a major part of the phosphate in the apatite form. It is expected that these products will be relatively more effective in soils with a high phosphate-retention capacity where the water-soluble phosphate will be available as a "starter nutrient" and the unreacted rock will continue to provide phosphate at a steady rate over a long period of time.

Conclusions from greenhouse results can be summarized as follows: (1) substantial increase in initial effectiveness of low reactivity rocks can be obtained by partial acidulation, (2) partial acidulation does not substantially improve the initial effectiveness of highly reactive rocks, and (3) partially acidulated products appear effective even when granulated to conventional size (minus 6- plus 14-mesh, Tyler). Experiments will be conducted to test these observations under field conditions.

Socioeconomic Research

The previous sections highlighted basic agronomic studies designed to determine the relationships between fertilizer source-soil-crop and management. To implement promising research station results at the farm level, both social and economic factors must be considered. In 1980 activities were directed toward interdisciplinary planning of on-farm research to identify the fertilizer technology components and management strategies appropriate to the circumstances of small farms in Colombia.

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Two characteristic features of small-farm agriculture in Colombia likely to influence adoption of fertilizer technology were selected for initial research: (1) practices associated with patterns of land use, in particular, the rotation with fallow, a substitute for fertilizer use and (2) manual minimum tillage techniques practiced in traditional steep-slope agriculture.

Data collection for field research followed a two-stage process: (1) exploratory survey—open-ended interviewing with key-informant farmers and (2) formal survey—structured interviews with a random sample of farmers to quantify and test hypotheses developed in the exploratory survey. Two distinct types of small farms can be identified with different implications for experimental research. A higher proportion of farms with limited land resources for maintaining a viable rotation with fallow adopt fertilizer technology for increased production by extending the cropping cycle on a plot.

Fertilizer technology testing for larger farm units with the land resources to sustain a rotation with fallow requires evaluation of the profitability of fertilizer applications relative to bringing fallow land into cultivation. Yields obtained within the rotation system are a baseline against which farmers will evaluate increments to production from fertilizer applications.

With regard to farmers' land preparation, techniques are not always readily compatible with experimental fertilizer application methods. For example, farmers who plant in isolated hills leaving untilled soil between hills would need to adjust land preparation techniques in order to adopt the practice of broadcast and incorporation of fertilizer. Small farmers in the research area do not experience problems with the application of nongranulated fertilizer because their application methods are adapted to this traditional planting method.

Future field research on the agronomic effectiveness of various forms of phosphates will take into account the conditions under which small farmers grow crops and their attitudes toward fertilizer use.

SPECIAL PHOSPHATE PROJECTS

Special studies involving phosphates continue to be a significant part of the overall program. In general, these studies are directed toward a particular problem ore for determining the most appropriate method(s) to utilize it. This type of work is requested and sponsored by companies or governments.

Improved Method for Slimes Disposal and Water Recovery in Phosphate Mining

Present phosphate mining and beneficiation techniques generate wet bulky slimes as wastes. The disposal of such waste is a difficult problem because the volume of the slimes may be larger than the original matrix. In some instances, the water lost in the slimes has a significant value.

One method to minimize the disposal problem and to recover water is to flocculate the slimes. The technique consists of flocculation of the slimes with polyethylene oxide (PEO) and removal of water from the flocs by a combination of wet-screening methods. The flocs are strong enough to pass a static screen, a horizontal vibratory screen, and a trommel. This concept, developed by the U.S. Bureau of Mines, appears to have application to slimes disposal in developing countries.

Technical Evaluation for Senegal Phosphate Slimes Utilization as Fertilizer

In Senegal about 0.8 million metric tons of phosphate continues to be disposed of per year as a 12% solids slurry, which contains about 25% P_2O_5 on a dry basis. Some characteristics of the slurry are: (1) it is very finely divided (more than 50% by weight of the solids is smaller than 2 microns) and (2) it is primarily apatite, about 63%, with iron- and aluminum-bearing clays composing the bulk of the impurities. No technology is known for the processing of this material. During 1980 IFDC continued its efforts directed toward production of 30% P_2O_5 phosphoric acid from these partially

Hydrocyclones are used to remove slimes from Senegal phosphate ore.

dewatered slimes. Tests were conducted in the IFDC bench-scale wet-process phosphoric acid unit. Different flow configurations of the dihydrate process as well as the hemihydrate-dihydrate process were tested. The effect of flocculants on gypsum filterability was investigated as part of this program. To obtain a favorable water balance, it was necessary to partially dewater the slimes using a pilot-plant-scale filter press. Cakes containing about 60% solids were obtained as concentrated slimes. In some tests, the feed slurry was diluted to about 41%-48% solids for ease in pumping the slurry to the laboratory-scale wet-process acid unit. In other tests, the slimes were fed to the unit in the dry state.

Acidulation tests were made in a single-tank reactor and a two-tank reactor system. Solids separation was done by using filtration or centrifugation. The main problem encountered was the difficulty in separating the solids from the phosphoric acid. Under all conditions tested, filtration rates were relatively low. Reaction efficiencies ranged from 70% to 80% using the dihydrate process and 99% by the hemihydrate-dihydrate process.

The effect of adding various flocculants to gypsum slurries obtained from the acidulation tests was studied by using various methods of addition and mixing. Four samples of about 100 g of fresh slurry were withdrawn from the reactor slurry and treated with different amounts of flocculant to obtain concentrations of 26, 130, 260, and 390 parts per million in the slurry. A sample of the treated slurry was then examined with an optical microscope. Some of the flocculants agglomerated the clay particles. From this screening test, the following flocculants seemed to be able to produce relatively large agglomerates (about 110 microns and larger): Nalco 7129, Nalco 7871, Nalco 7872, Nalco 7873, Calgon L-650E, Calgon L-670E, Polyhall 990, Polyhall 295. Some of the results indicated that agglomerates of sizes up to about 600-800 microns could be formed. This study did not include tests of the effect of flocculants on filtration; therefore, the stability of these agglomerates during filtration is not known. Further work is required for optimization studies to determine the best flocculant for the system. If a practical solids-liquid separation technique can be found, recovery of P_2O_5 values from phosphate slimes would be more attractive technically. Continuation of the project is dependent on funding from the sponsor.

Sri Lanka Eppawala Phosphate Rock Study

IFDC completed a 1-year study that was begun in early 1979 to determine the potential uses of a phosphate rock from Eppawala, Sri Lanka. The Eppawala phosphate deposit in Sri Lanka, estimated to contain 25 million metric tons of P_2O_5, is sufficient to provide the needs of Sri Lanka for many years. With cooperative financial support from Dienst Internationale Technische Hulp (DITH) of the Netherlands, IFDC carried out laboratory and greenhouse studies to evaluate the performance of experimental products made from this rock.

IFDC completed a 1-year study that was begun in early 1979 to determine the potential uses of a phosphate rock from Eppawala, Sri Lanka.

This high-grade rock (36.4% P_2O_5) was treated in an attempt to reduce the primary impurities, chloride (1.1%), iron, and aluminum oxides (6.7%), to acceptable levels.

Conversion of the rock to wet-process phosphoric acid resulted in a filter-grade acid containing 27% P_2O_5 having a relatively high chloride content. Phosphoric acids having a high chloride content are very corrosive and require special materials of construction for their manufacture. Of the stainless-steel materials tested with this acid, Sanicro 28 and Jessop 700 were the best. When concentrated, the filter-grade acid (27% P_2O_5) produced a very viscous merchant-grade acid containing 54% P_2O_5.

Ammoniation of the concentrated acid produced a high-grade DAP (18-48-0) and monoammonium phosphate (MAP) (13-51-0), but no attempt was made to granulate the products. SSP and TSP also were produced satisfactorily for agronomic testing but not in granular form. Rhenania-type phosphate (0-26-0) and a fused calcium-magnesium phosphate (0-20-0) were other products also made for agronomic testing.

Agronomic evaluation of some products by incubation and greenhouse testing for phosphate availability showed that TSP, SSP, and Rhenania-type phosphate made from Eppawala rock were the most effective of the materials tested. As a source for phosphate, the finely ground rock was relatively ineffective in direct application as compared with the other sources. MAP and DAP were made but not agronomically evaluated.

Kodjari Phosphate Rock in Upper Volta for Phosphate Fertilizer Production

IFDC continued its efforts to determine the best method for utilizing Kodjari phosphate rock (a relatively unreactive rock) for production of agronomically effective phosphate fertilizer. This project began in late 1979 when Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) asked IFDC to undertake the project to: (1) characterize the rock, (2) recommend products for larger scale production, (3) develop laboratory data for scale-up to pilot-plant testing, (4) carry out soil-incubation and greenhouse tests on products, and (5) provide preliminary

IFDC continued its efforts to determine the best method for utilizing Kodjari phosphate rock for production of agronomically effective phosphate fertilizer.

production economics on one or more processes and products selected for pilot-plant and field testing.

Kodjari phosphate rock contains about 60% apatite (25.4% P_2O_5). In laboratory-scale studies the rock did not appear suitable for SSP production; the product was too sticky and low in available phosphate. TSP was not produced because phosphoric acid of the required concentration and acceptable handling properties could not be prepared from this ore. Partially acidulated products, using lower levels of phosphoric acid than normally used to make TSP, were made in finely ground, minigranulated, and granulated forms. The water-soluble phosphate in the products increased with an increase in granule size, while the total availability (water-soluble plus citrate-soluble phosphate) remained constant. Phosphoric acid made in a clinker-type process contained up to 63% P_2O_5. However, 40% P_2O_5 phosphoric acid was the maximum concentration obtained that did not precipitate large amounts of solids during storage for a few days.

Agronomic studies in the greenhouse indicated that finely ground Kodjari phosphate rock was relatively ineffective as a phosphate fertilizer for a short-term maize crop. The most effective product was the finely ground phosphate fertilizer produced by acidulation with 30% of the phosphoric acid required for TSP; this product was 89% as effective as TSP. Results of the soil-incubation studies showed that relative agronomic effectiveness increased with water solubility. The addition of elemental sulfur to the finely ground rock did not enhance the dissolution of the Kodjari phosphate rock in soil.

A counterpart engineer from Upper Volta spent time at IFDC Headquarters to participate in the preparation of the fertilizer materials. The next phase of this project will deal with agronomic evaluation in Upper Volta of a few products that show promise.

The most effective product was the finely ground phosphate fertilizer, produced by acidulation with 30% of the phosphoric acid required for TSP; this product was 89% as effective as TSP.

Granulation of Phosphate Fines From Jordan

IFDC studied ways to granulate a fines fraction of phosphate rock from Jordan. The product might be used as a direct application fertilizer or used in chemical processing. Dustiness of the fines is causing a serious handling problem for transportation and shipping.

IFDC studied ways to granulate a fines fraction of phosphate rock from Jordan. The product might be used as a direct application fertilizer or used in chemical processing.

A determination of particle-size range showed that the fines contained a fraction, at least 25% by weight, that would be relatively nondusty and that a simple screening operation would recover this portion of the fines as an acceptable product without any agglomeration. The remaining fraction could then be granulated for blending with concentrate.

In laboratory granulation tests with binders, such as water-soluble salt solutions and acid solutions, IFDC demonstrated the feasibility of granulating the finer fraction of the fines into products having acceptable physical properties for blending with the coarser size fractions of concentrate. The binders should not interfere with use of the granulated product for further chemical processing.

Pilot-plant work is needed to provide engineering data and to develop the preliminary economics of production.

Although the results of this study are being directed toward a specific problem in Jordan, they can also be applied to other phosphate-producing countries faced with the same or a similar problem.

Togo Phosphate Rock Characterization Studies

At the request of the World Bank, IFDC completed a cursory mineral study of 19 phosphate rock samples from Togo to identify the ore types and variations in the beds immediately underlying their present deposit. It was found that ore similar in type to that presently produced could be mined by deepening their present operation. This action would expand the operating life of their mine. In a followup study, the company sent 56 drill cores to IFDC for detailed study. This investigation continued into 1981.

Sardinata Phosphate Rock (Colombia) for Nitric Phosphates

IFDC continued to assist Monomeros Colombo Venezolanos, S.A. (MONOMEROS), in utilizing Sardinata phosphate rock for the manufacture of nitric phosphate fertilizer. In 1978 MONOMEROS began using small quantities of Sardinata rock mixed with imported Florida phosphate rock in its nitric phosphate plant. Because of process difficulties, the proportion of Sardinata rock that could be used was limited to 5% of the blended feed. In late 1979 and early 1980, IFDC studied the MONOMEROS type of nitric phosphate process using bench-scale equipment.

IFDC continued to assist Monomeros Colombo Venezolanos, S.A., in utilizing Sardinata phosphate rock for the manufacture of nitric phosphate fertilizer.

Under conditions tested in the IFDC laboratory, the filtration rate of the gypsum slurry from Sardinata rock was comparable to that of the gypsum slurry from Florida rock. The overall phosphate recovery was lower for Sardinata as compared with that of the Florida rock. The difference resulted from variations in washing efficiency of the gypsum cake. Additional washing of the Sardinata filter cake should improve its recovery. Under conditions of high sulfate and intense agitation, the Sardinata filter cakes showed a decline in filtration rates. With relatively minor modifications, the plant at MONOMEROS should be able to utilize straight Sardinata rock, but a full-scale plant test is needed to confirm these laboratory findings.

Evaluation of Abu Tartur Phosphate Rock

A study was completed for the Egyptian General Executive Organization for the Industrial and Mining Complexes (IMC) to conduct (1) a greenhouse evaluation of finely ground Abu Tartur phosphate rock for direct application to soil (acid and basic types) and (2) an evaluation of Abu Tartur matrix and concentrate for conversion into wet-process phosphoric acid in laboratory scale.

The greenhouse test comprised the growth of maize in acid (Mountview, pH 5.0) and alkaline (Crowley, pH 7.9) soils. Fertilizer application rates were up to 800 parts per million phosphate. Residual effects were measured on a second crop. The known reactive rocks from Gafsa (Tunisia) and North Carolina (United States) and commercial TSP were tested in parallel for comparison.

The wet-process phosphoric acid processes tested included the standard dihydrate process, the new Nissan C process, hemidihydrate, and some less conventional dihydrate processes. No further tests are planned at this time.

With relatively minor modifications, the plant at MONOMEROS should be able to utilize straight Sardinata rock, ...

Sulfur Research

Efforts of the IFDC Sulfur Research Program concentrated on developing Headquarters' laboratory and greenhouse research methodologies and techniques. Studies were conducted to identify soil and climatic conditions and management factors that contribute to the development of sulfur deficiency. To provide guidelines for 1981 field research on sulfur, special emphasis was placed on studying the factors that limit the efficiency of sulfur fertilizers.

STUDIES ON THE EFFECT OF LEACHING AND LIMING ON SULFUR DEFICIENCY AND SULFUR RESPONSE

Little is known about the soil and climatic factors that lead to a sulfur deficiency in the tropics. Knowledge concerning the factors controlling sulfur response, however, is essential not only for the identification of sulfur- deficient areas but also for the development of proper sulfur-diagnostic techniques and efficient sulfur fertilizer sources.

Research conducted in several tropical savanna regions, particularly in Africa, Oceania, and Southeast Asia, has shown that a sulfur deficiency frequently occurs in sandy soils in areas with a high seasonal rainfall intensity. These findings indicate that leaching of the sulfur as sulfate may be one of the important mechanisms contributing to the development of a sulfur deficiency in tropical soils.

Temperate zone research, primarily in the United States, also has shown that liming an acid soil may greatly increase the sulfate leaching losses. Liming is an agricultural practice likely to increase in many tropical savanna areas, particularly in the acid soils of South America. Such areas also are likely to be inherently sulfur deficient because of their low available soil sulfur content and the low atmospheric sulfur returns.

During 1980 IFDC conducted a series of greenhouse experiments to assess the effects of leaching and liming on sulfur deficiency and sulfur response in acid soils. The soils used were Mountview silt loam and Hartsells silt loam subsoil. The soils were incubated for 2 weeks with various rates of lime and then leached with distilled water at an average rate of 1 cm/day for an additional 2 weeks. The control soils were incubated with lime for 4 weeks at field moisture capacity but were not leached. The pH of the limed soils was 4.3, 4.7, 5.0, 5.4, and 5.7 for the Mountview soil and 4.4, 6.3, 6.8, and 7.1 for the Hartsells subsoil.

During 1980 IFDC conducted a series of greenhouse experiments to assess the effects of leaching and liming on sulfur deficiency and sulfur response in acid soils.

Following the liming and leaching, the soils were mixed with various rates of gypsum and basal fertilizers (monocalcium phosphate, ammonium nitrate, potassium chloride, and micronutrients) and cropped to corn for two consecutive harvests of 5 weeks each.

Liming greatly increased the amount of sulfate leached, particularly in the Hartsells subsoil. The leaching losses occurred very rapidly, indicating low retention of the soil sulfate. The sulfate leaching losses generally increased with an increase in the rate of liming.

In the leached soils, significant increase in the dry-matter production due to the addition of gypsum was obtained (Figure 11); this indicated that the soil was sulfur deficient. Liming increased the magnitude of sulfur deficiency in the leached soils. In contrast, in the unleached control soils liming generally resulted in an increase in the dry-matter production, and no significant effect of gypsum was obtained.

In a field application it is a common practice to lime the soil several weeks before planting to allow lime the time to react with the soil. Our study indicates that this may result in the development of sulfur deficiencies, particularly if the planting time coincides with heavy rains such as at the onset of the rainy season in the tropics. Therefore, it appears that timing the lime application may be an

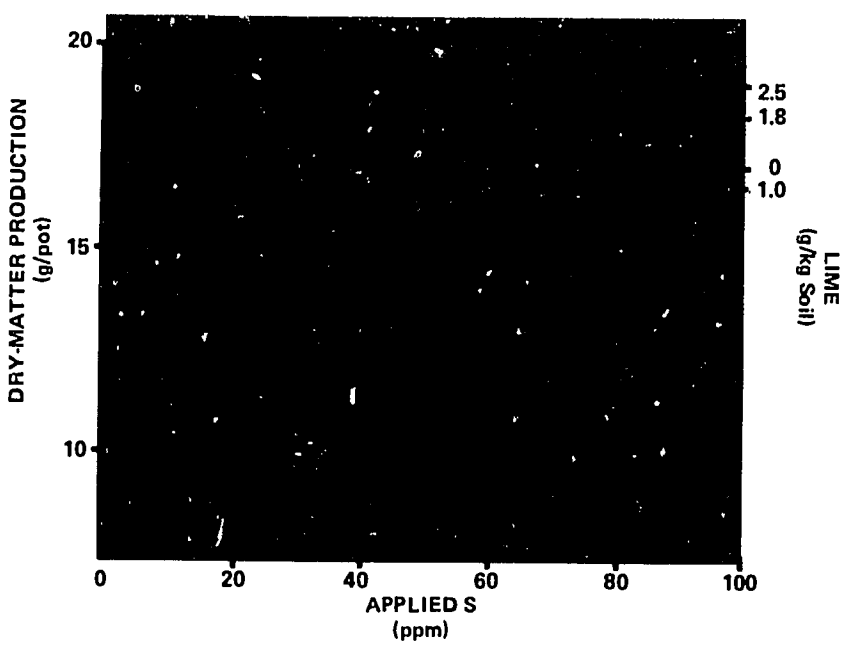

Figure 11. The Effect of Liming on Sulfur Response in Leached Soil.

important factor in preventing the potential yield losses due to the lime-induced sulfur deficiency. This possibility needs verification through field trials.

THE EFFECTS OF LEACHING RATE, PARTICLE SIZE, AND SOURCE ON THE AGRONOMIC EFFICIENCY OF SULFUR FERTILIZERS

Studies were also conducted at IFDC Headquarters to assess the effect of leaching on the agronomic efficiency of sulfur fertilizers. In the first set of experiments the effect of leaching rate on sulfate losses and the agronomic efficiency of gypsum were studied. The soil was amended with powdered gypsum at the rate of 0, 10, 20, and 40 parts per million sulfur and cropped to corn for two consecutive harvests, 4 weeks each. The pots were leached with water at the average rates of 0.91, 2.20, and 4.20 mm/day for the first harvest and were left unleached for the second growing season.

Sulfate was leached from the soils at a rate approximately proportional to the amount of gypsum added and the volume of solution passing through the soil. The apparent amounts of gypsum removed by leaching varied from 8% to 58% of the amount added for the 0.91-mm/day and 4.2-mm/day flow rates, respectively. Increasing the gypsum application rate increased the apparent sulfate losses. The study indicated that in soils with a low sulfate-sorption capacity recovery of applied gypsum fertilizer is significantly lowered due to the sulfate leaching losses. In such areas powdered gypsum is likely to be an inefficient source of sulfur, thus necessitating the use of low-solubility sources of sulfur, such as elemental sulfur and pyrite.

Experiments to assess the effects of source, particle size, and rate of application on sulfur fertilizer were conducted. The sources used were gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and elemental sulfur. The particle sizes were: powder (minus 150-mesh), -3.4 + 2.4 mm, and -6.3 + 3.4 mm for gypsum, anhydrite, and powdered elemental sulfur, respectively. The rates of sulfur application were 10 and 40 parts per million sulfur, and the average rate of leaching was 1.9 mm/day. The soil was planted to corn, and two consecutive crops, 5 weeks each, were grown.

The sulfate leaching losses from the fertilizer sources are shown in Figure 12. The amounts of sulfate leached varied from 1.8% to 67.0% of the amounts applied. Granulation significantly reduced the leaching losses, especially for gypsum, from 67% losses versus 8% losses for the powdered and the -6.3 + 3.4 mm granulated material, respectively. Increasing the rate of sulfur applied increased the leaching losses. The losses for powdered anhydrite and elemental sulfur were significantly less than those for gypsum. In contrast, there was no significant leaching loss difference between the two granulated materials (gypsum and anhydrite). Analysis of the agronomic data of the experiment is continuing.

The research conducted at IFDC Headquarters has identified sulfate leaching as an important mechanism limiting the efficiency of applied sulfur fertilizers. Future work will involve the development of greenhouse and field testing of modified or new sulfur fertilizer sources, with slow-release characteristics, in an effort to decrease the sulfate leaching losses.

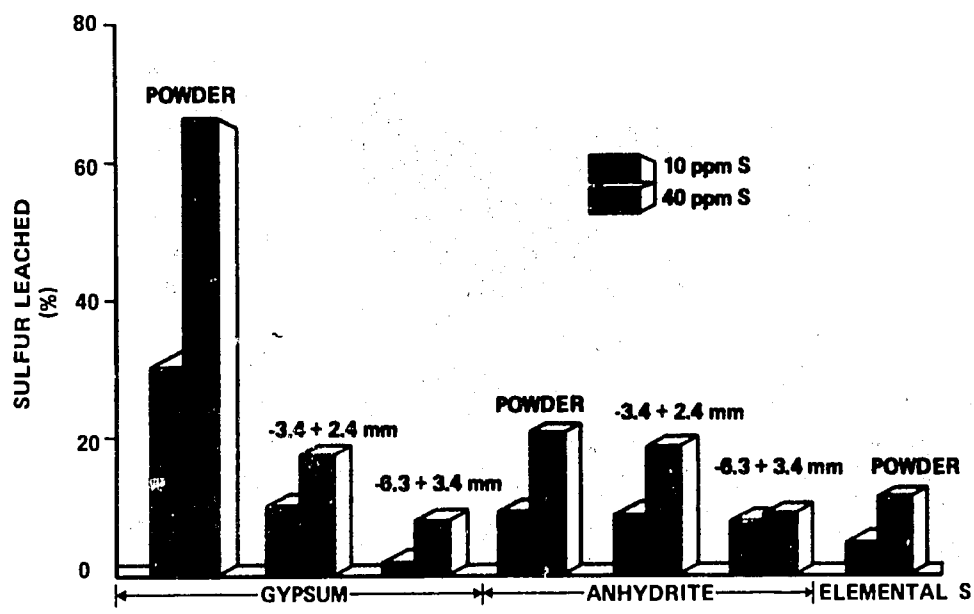

Figure 12. The Effect of Source, Particle Size, and Sulfur Rate on Sulfate Leaching Losses From Fertilizer Materials.

Economics Research

If a new fertilizer technology is to be accepted by farmers in a developing country, it must be economically superior to the technologies already existing there. Other factors influencing its acceptance include the physical and socioeconomic environment and policies of national and local institutions.

Accordingly, IFDC economics research is designed to generate information for developing policies to promote the economical use of fertilizers. The main objectives of this policy research are (1) to identify alternatives for the development of a fertilizer sector and evaluate their potential to achieve stated national goals, (2) to generate relevant information in formulating appropriate fertilizer policies, and (3) to provide guidelines for designing, implementing, and monitoring national fertilizer policies.

IFDC economics research is designed to generate information for developing policies to promote the economical use of fertilizers.

EQUITY EFFECTS OF FERTILIZER USE

IFDC and the Bangladesh Agricultural Research Council (BARC) jointly undertook, at the request of USAID/Bangladesh and Bangladesh Agricultural Development Corporation (BADC), a study to determine (1) the degree to which the benefits of fertilizer use in Bangladesh are shared by different classes of farmers and (2) the extent to which fertilizer helps create employment in agriculture. A detailed farm survey at 10 different locations, covering 1,053 farms, was carried out for the Aman 1979 crop. The results of a preliminary report prepared in April 1980 indicate that (1) a larger percentage of small-farm landholders (compared with larger farmers) use fertilizer and that they use more fertilizer per unit of land, (2) the benefits of fertilizer use are fairly well distributed among different farm classes, and (3) fertilizer use increases employment of rural labor to a considerable degree.

The data indicate that small-farm landholders receive higher yields of rice than those operating larger farms because of the greater fertilizer use per acre. They also retain more net benefits after paying the fertilizer costs and the rent of sharecropped land.

In addition to the direct benefits to farmers, fertilizer use has important indirect benefits in the form of increased employment of labor and other inputs. On an average for the sample, fertilizer use increased the employment of hired labor by 2.7 workdays/acre of cultivated land. This is approximately a 14% increase in employment due to fertilizer use. The increase, however, is much greater (5.61 workdays/acre) in the case of HYVs grown under irrigated conditions.

The detailed findings of this research were presented to representatives of the Government of Bangladesh, BADC, USAID/Dacca, and other development agencies in Dacca during 1980. The survey has since been expanded to cover six additional locations and three subsequent crop seasons terminating with Aman 1980. The data will be analyzed during 1981.

ADDITIONAL SURVEYS

The following field surveys relating to fertilizer adoption and demand were completed during 1980.

1. A joint field survey between BARC and IFDC covering 480 farms for four seasons was completed at the beginning of 1980. The data being analyzed include plotwise soil analysis information.
2. Fieldwork for the joint project between HFC of India and IFDC was completed during late summer of 1980. This project covered 20 locations (3,000 farms) in five states in eastern India for the summer season, 1979, and winter season, 1979/80. The data, now being coded in Calcutta, include soil analysis.

GENERAL POLICY STUDIES

The general fertilizer policy studies consisted of two projects: (1) leading economic indicators for fertilizer sector planning and policymaking and (2) principal policy issues facing the fertilizer sector in Africa.

Fertilizer policies based on inappropriate statistics and/or information often result in wastage of national resources. The "leading economic indicators" project initiated during 1980 was designed to partially correct this problem. The purpose of this project was to develop an analytical framework that will provide guidelines to generate relevant fertilizer statistics and information. The project is continuing with a focus on specific case studies from Asia, Africa, and Latin America.

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The purpose of the second project was to provide an analytical perspective on the principal public policy issues facing the fertilizer sector in Africa. The selected economic indicators reflect that the fertilizer sector in Africa is passing through the initial stages of development. For example, during 1979/80 Africa accounted for less than 3% of the world's fertilizer consumption. Fertilizer use, especially on food crops, is extremely low. Fertilizer production facilities are either nonexistent or in most cases

operate inefficiently. Food deficits are large and expanding. In many cases, crop yields are declining.

The study deals with 38 countries in Africa. For the purpose of this analysis the African continent was divided into four regions consisting of north, south, east, and west Africa. There are major exceptions, but the selected general findings and policy recommendations are discussed below.

1. Although many African countries possess large potential for agricultural production, they lack clear priorities and national commitment to exploit the agricultural potential through appropriate incentives, technology, institutions, and infrastructure. A positive agricultural policy is necessary for the development of a viable fertilizer policy.
2. Except for Egypt, South Africa, Zimbabwe, and Senegal (Figure 13), the level and growth in average fertilizer use are generally low.
3. Countries with negative growth in fertilizer use are those countries that exclusively depend on imports.

Although many African countries possess large potential for agricultural production, they lack clear priorities and national commitment to exploit the agricultural potential through appropriate incentives, technology, institutions, and infrastructure.

4. Most African nations depend on fertilizer imports to meet part or all of their domestic requirements.
5. Financing imports of fertilizers or development of a domestic industry does not seem to receive the priority commensurate with its potential to contribute to the economic and agricultural development of the nation. It is estimated that in the next 6 years Africa needs at least US $11 billion (1980 dollars) to finance imports or domestic production to meet its projected fertilizer consumption.
6. Greater emphasis is needed on fertilizer research to explore and/or develop Africa's indigenous resources, such as phosphate rock reserves, of which it has 82% of the world's total.
7. Most African countries need well-developed and responsive institutions to deal with agricultural research, extension, marketing, and input deliveries.

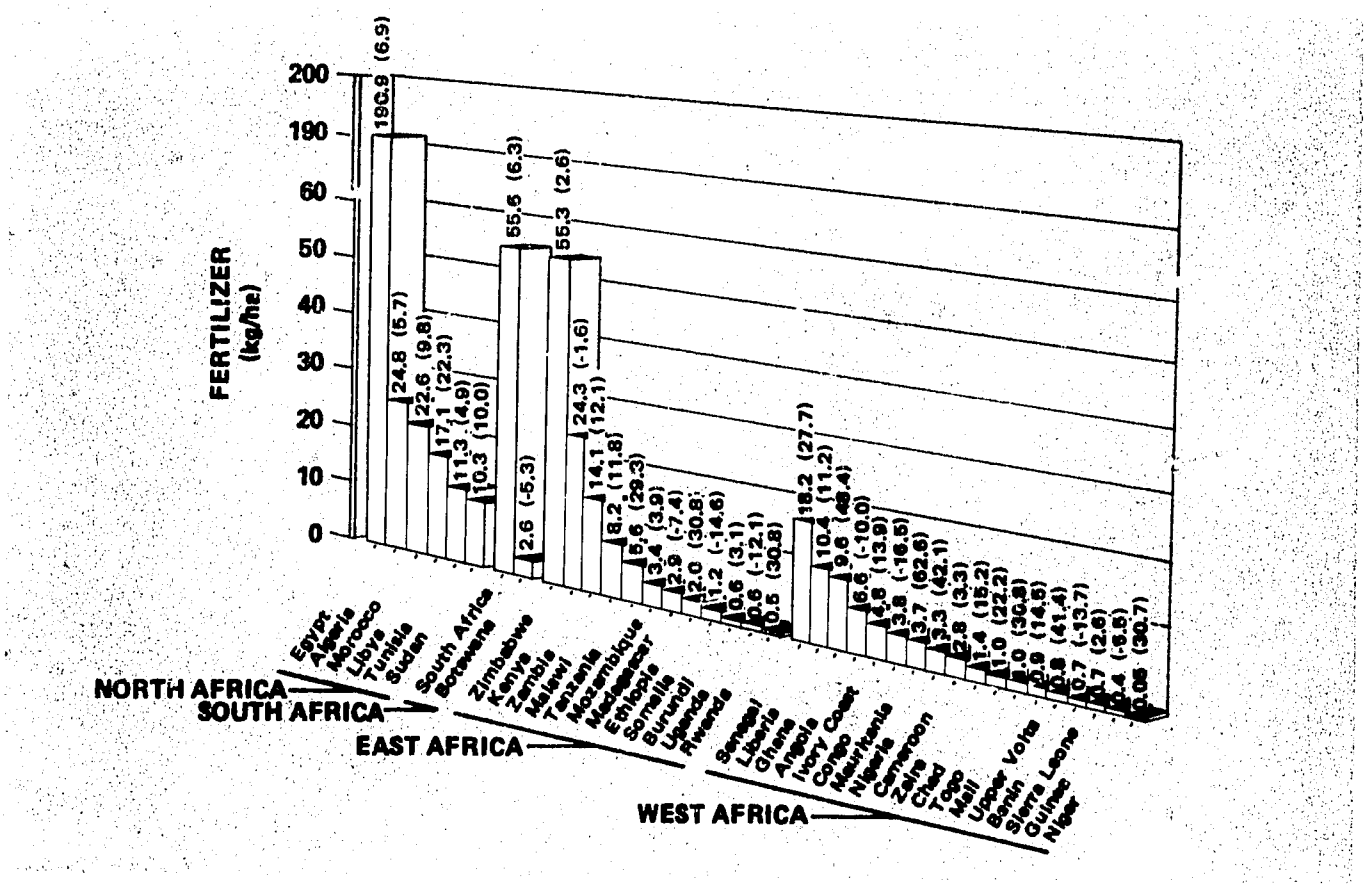

Figure 13. Fertilizer Consumption in Africa, Kilogram per Hectare of Arable Land and Permanent Crops, 1975-77 Averages. Figures in Parentheses Are: Annual Compound Growth Rate in Fertilizer Use Per Hectare From 1969-71 to 1975-79.

8. The most serious constraint to the development of fertilizer and agricultural sectors in Africa appears to be the lack of trained manpower.

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CROP SPECIFIC (RICE) POLICY STUDIES

The project on rice policies in Southeast Asia is a continuation of the project initiated during 1979. It is a collaborative effort between the International Food Policy Research Institute (IFPRI), IFDC, and IRRI. The major focus of the project is on evaluating alternative policies to expand national rice production and maintain rice price stability.

The preliminary Phase I reports of the project are being completed, and preparations have been made to initiate Phase II of the project. Initial results were discussed at a UNDP-financed workshop held in Singapore, October 1980. Some of the highlights of Phase I of the project are summarized below:

1. With the exception of Malaysia (oil palms and rubber are major crops), the rice sector accounts for approximately one-half of the fertilizer use. In Indonesia the proportion of fertilizer use on rice is about 75%.
2. Fertilizer use is expanding rapidly. The average use during 1979 was approximately 44, 103, 35, and 17 kg/ha in Indonesia, Malaysia, the Philippines, and Thailand, respectively.
3. Fertilizer supply (especially domestic production) and availability at the farm level (marketing) appear to be major factors in expanding fertilizer use. During 1979/80 fertilizer self-sufficiency in Indonesia, Malaysia, the Philippines, and Thailand was estimated to be 109%, 15%, 22%, and less than 1%, respectively.
4. Correcting existing inefficiencies in the fertilizer marketing system can not only make fertilizer available to the farmer on time but also at lower prices.
5. Among the Association of Southeast Asian Nations (ASEAN) countries, Indonesia has a highly developed fertilizer sector. It has efficiently operated plants and a modern distribution system. The government has been able to create the minimum infrastructure and institutions needed for fertilizer use expansion.

ENERGY POLICY STUDY

Energy is a major input in fertilizer manufacturing and transportation, especially nitrogen fertilizers, which depend upon nonrenewable energy for both feedstock and fuel. Recent increases in energy prices have resulted in substantial increases in fertilizer production costs, freight rates, and fertilizer prices.

IFDC initiated an energy and fertilizer study in response to a request from USAID in the latter part of 1980. In addition to determining energy requirements in the fertilizer sector and the impact of energy on fertilizer production and prices, alternative means to minimize the impact of high energy prices and energy supply on fertilizer production costs and prices will be examined. The study will be completed during 1981.

IFDC initiated an energy and fertilizer study in response to a request from USAID in the latter part of 1980.

GLOBAL FERTILIZER (NITROGEN) POLICY STUDY

Of the total fertilizer nutrients consumed in the world, approximately one-half (more than one-half in developing countries) is nitrogen. While nitrogen fertilizers can be produced from several alternative sources of feedstock, they are highly energy intensive and, in most cases, depend on nonrenewable energy resources. Furthermore, a major portion of applied nitrogen is lost. In addition, biological fixation and organic fertilizers are also major sources of nitrogen. For these reasons an analysis of these issues is extremely important for designing strategies to supply nitrogen for expanding food production.

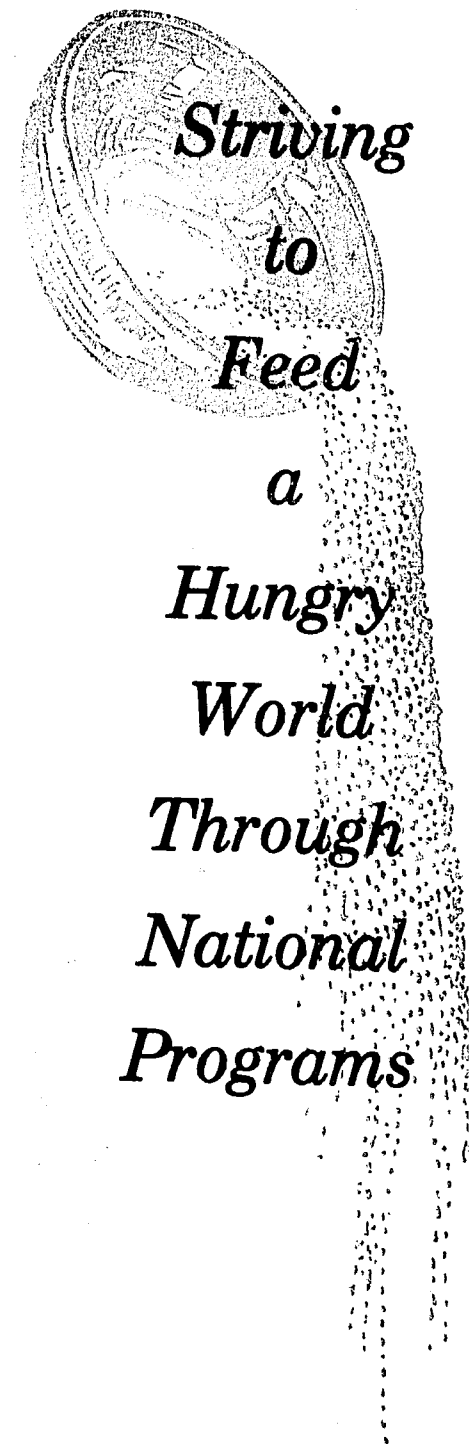
In recognition of this, IFDC has initiated a joint multiyear collaborative project with the Institute for Agricultural Market Research of the Agricultural Research Center, Braunschweig, Voelkenrode, West Germany. During 1980 a followup to the joint research proposal was completed. The main purpose of this followup was to identify the scope, methodology, and data needs for each aspect of the project. Appropriate data were collected from secondary sources and organized into appropriate formats. This study is expected to generate much relevant information concerning nitrogen fertilizer trade, production, prices, research, and technical and financial assistance for national and international decisionmakers.

National Programs

The developing countries provide a vehicle through which the relevant fertilizer problems can be identified and quantified and the resultant technology developed by IFDC and others in response to these problems can be tested as to its applicability to the fertilizer sector and the farmers of their countries.

The ultimate goal of IFDC is to produce technology that is useful to both the fertilizer sector and the farmers of the developing world. Such technology would contribute not only to an increase in food production but also to the economic well-being of the people of the Third World. IFDC recognizes that this goal cannot be realized without the full partnership, commitment, and participation of key institutions within each developing country. Therefore, IFDC is actively involved in developing mechanisms to achieve this partnership.

This partnership is taking the form of the establishment of national fertilizer programs where fertilizer is considered vital to the economic development of a particular country. In establishing such relationships, IFDC brings to bear a multidisciplinary uniqueness in that it possesses the essential expertise in the areas of production, marketing, and use of fertilizer that will allow the creation and further development of a strong national fertilizer program. The developing countries provide a vehicle through which the relevant fertilizer problems can be identified and quantified and the resultant technology developed by IFDC and others in response to these problems can be tested as to its applicability to the fertilizer sector and the farmers of their countries.



Bangladesh

An IFDC contract with BADC implemented in 1979 was extended through August 1981. IFDC is providing a wide range of technical assistance through this contract. Much of this assistance is provided directly to BADC and is aimed at improving its marketing and distribution capabilities. Other assistance also financed through the contract is being provided to other government institutions concerned with fertilizer and whose actions are likely to affect the eventual performance of BADC. The study with BARC aimed at determining the equity effects of fertilizer use on farms is an example of this assistance.

MARKETING AND DISTRIBUTION ASSISTANCE

The IFDC/BADC consultancy contract is part of USAID's "Bangladesh Fertilizer Distribution Improvement Project," which has as its goal increasing food grain production especially among small farmers through increased use of fertilizers on an equitable basis by removing fertilizer supply and marketing-related constraints.

BADC, a government-owned corporation, is responsible for importing, marketing, and distributing all fertilizer except ammonium sulfate in Bangladesh. Fertilizer consumption has increased from 130,000 nutrient tons in 1969/70 to 400,000 nutrient tons in 1979/80. A new marketing system was introduced by BADC in late 1978 in one of the four marketing divisions in the country. The new marketing system was designed to reduce marketing and distribution constraints, expand the role of the private sector in fertilizer marketing, and improve farmers' access to fertilizer. In 1980 the new marketing system was expanded to cover the entire country.

Two IFDC consultants outposted in Dacca, assisted by short-term experts from IFDC Headquarters, monitored and provided recommendations on the new marketing system's implementation. IFDC consultants carried out in-depth analysis of BADC marketing costs for the last 5-year period, made fertilizer sales projections and agronomic fertilizer requirement projections, prepared distribution programs taking into account an anticipated major increase in domestic urea production from the new Ashuganj factory, and completed a comprehensive evaluation report of the new marketing system. A review of inventory control and accounting systems was initiated; results of the review and recommendations will be presented to BADC in early 1981.

IFDC's findings as of December 1980 reveal that the new marketing system has increased farmers' access to fertilizer sources, comparatively lowered retail prices, consolidated government warehousing, and had minimal effect on the costs of government distribution. The new system has not worked well in underdeveloped areas where transportation and communications are inadequate and where fertilizer sales are low. The new marketing system is still in the early stages of transition and development; additional modifications are under consideration.

Under the contract, IFDC has now provided marketing training outside Bangladesh for a total of 21 marketing managers. The development of dealer training programs within BADC to capitalize on this corps of expertise is underway.

EQUITY STUDY

At the request of USAID/Bangladesh and BADC, IFDC and BARC initiated a study to determine the equity effects of fertilizer use in Bangladesh. The results of this study are discussed in the Economics Research section.

FERTILIZER SUPPLY AND USE POLICY STUDY

The Chairman of BADC, aware of the increasing complexity of soil fertility problems that are potential constraints to efficient fertilizer use, requested the development of a study to cover all aspects of fertilizer use in Bangladesh. The study will identify problems to be faced in developing a greater role for various fertilizers, secondary and trace elements, and organic materials in increasing food production and will highlight the major policy issues. Terms of reference for the study and choice of the multidisciplinary team of Bangladesh experts to work on the study, which will be a consensus document, were finalized in November 1980.

Indonesia

FERTILIZER EFFICIENCY PROGRAM

During 1980 IFDC continued its cooperative activities with Indonesian scientists in their efforts to increase agricultural production in Indonesia through more efficient use of fertilizers. Scientists from Indonesia, IRRI, and IFDC met at IFDC Headquarters in September 1979 to establish a strategy and planning document for the fertilizer efficiency program. In April 1980 the program was approved by the Government of Indonesia. The Agency for Agricultural Research and Development, Ministry of Agriculture, in cooperation with the Directorate General of Food Crops, Ministry of Agriculture; the Directorate General of Basic Chemical Industry, Ministry of Industry; and P. T. Pupuk Sriwidjaja (PUSRI), then hosted a "National Workshop on the Efficiency of Fertilizer" in Jakarta in which ways were discussed to properly implement the program. IFDC staff participated in this activity.

An interministry technical committee was established at the workshop to coordinate the development of a 5-year plan to suggest priorities of work in fertilizer production, marketing, and use. The committee will work through four workgroups—lowland rice, upland crops, socioeconomics, and fertilizer production and marketing—to develop detailed workplans and budgets, monitor activities, and evaluate and report the results of each activity area.

The fertilizer efficiency program encompasses various research and development activities essential in identifying ways to more efficiently utilize fertilizer-related resources in the agricultural and rural development of Indonesia. The program's research and action-related activities include product and marketing development; basic, applied, and adaptive research on fertilizer efficiency in lowland and upland cropping systems; and the gathering and analysis of a wide range of socioeconomic information essential for the development of policies and programs that will facilitate efficient utilization of fertilizers as a developmental resource at both the farm and national levels. This program is expected to provide the Government of Indonesia with an information base that can lead to more effectively utilizing fertilizer-related resources in Indonesia's efforts to accelerate food and agricultural production, strengthen the overall Indonesian economy, and increase the nutrition and income levels of Indonesian farmers.

PUSRI UREA GRANULATION PROJECT

Since 1975 PUSRI has been engaged in a project to convert one of their urea prilling units (PUSRI I) to the production of granular urea. The project is nearing completion, with plant commissioning and startup scheduled for early 1981. IFDC staff members have served as technical advisors to PUSRI from the project's inception, with PUSRI personnel completing the detailed engineering and construction phase of the project.

The plant, which will utilize the pan granulation process developed by TVA, represents the first effort to produce modified urea products outside North America and Europe. It is also the first commercial plant in the world to utilize the TVA process for granulating urea. The plant will produce in excess of 100,000 metric tons per year of product in the 2- to 4-mm size range.

During 1980 IFDC technical staff reviewed the progress of the technical requirements for the plant and answered inquiries from PUSRI. Two technical reviews were conducted onsite in 1980, with one IFDC representative visiting the plant to observe construction and answer PUSRI inquiries. IFDC has tentatively identified three personnel to assist PUSRI in plant startup/operation. When the granulation project is completed and the plant is onstream, the product from PUSRI I is expected to be used in the national program to improve nitrogen efficiency at the farm level through the deep placement or coating of granular urea.

Preparation is being made for the construction of the P.T. PUSRI urea granulation plant in Indonesia.

Technical Assistance

. . . a significant portion of IFDC's efforts is devoted to providing technical assistance requiring that staff members, with relatively short notice, be made available to help improve, for example, the production capability of a specific fertilizer plant, increase the effectiveness of a distribution system, make a decision relative to pricing policy, or provide guidance on future investments in fertilizer capacity or distribution.

IFDC was established to serve developing countries and specifically to help them meet their fertilizer needs. These needs are met in many ways, including research and development that leads to new and/or improved technology and training that will build a needed manpower base. Often, these needs are met as short-term technical assistance in response to solving specific problems that currently hamper the performance of the fertilizer sector. These requests often require immediate assistance. As a result, a significant portion of IFDC's efforts is devoted to providing technical assistance requiring that staff members, with relatively short notice, be made available to help improve, for example, the production capability of a specific fertilizer plant, increase the effectiveness of a distribution system, make a decision relative to pricing policy, or provide guidance on future investments in fertilizer capacity or distribution.

Sometimes these requests can be handled by telex or other normal communication channels. However, in a large number of instances, they require that staff members work face-to-face in-country with counterparts for periods of several weeks to several months to help solve a particular problem. This report covers only those requests that required significant manpower input. It does not describe the more than 750 inquiries that were handled routinely through brief 1-day visits, cables, letters, or other means of communication.

Left—*An IFDC-trained agricultural assistant explains the use of a mini-kit to a Nigerian farmer. The kit contains all of the crop production inputs (seeds, fertilizers, pesticides) necessary for one plot.*

Africa

EGYPTIAN NATIONAL RESEARCH CENTRE

Technical assistance was provided to the Egyptian National Research Centre (ENRC) to improve ENRC's capability to carry out phosphate research. Two ENRC engineers spent 2 months at IFDC for training in laboratory-scale and pilot-scale wet-process phosphoric acid production as well as pilot-scale beneficiation of phosphate rock. They also attended the 13th TVA technology demonstration and visited commercial companies in the United States to observe phosphate rock mining, beneficiation, and chemical processing. This program is a continuing effort involving study programs at IFDC for ENRC personnel and visits of IFDC personnel to Egypt. The National Academy of Sciences (NAS) project also involves supplying ENRC researchers with new equipment to strengthen their research capability.

Technical assistance was provided to the Egyptian National Research Centre (ENRC) to improve ENRC's capability to carry out phosphate research.

NIGERIA FERTILIZER MARKETING STUDY

In late 1979 the Federal Republic of Nigeria commissioned IFDC to conduct a fertilizer marketing study for Nigeria that would assess the distribution system, identify constraints to the supply and consumption of fertilizers, and recommend a marketing system designed to consume and deliver in the domestic market the full production of a proposed nitrogen plant at Port Harcourt.

The proposed nitrogen plant is scheduled to produce 1,000 metric tons of ammonia per day that will be used to provide 590,000 metric tons of urea per year. The 75,000 metric tons of SSP produced by the Kaduna superphosphate plant also is to be marketed by the new marketing system.

The recommended marketing system, when implemented, will be able to meet its target of marketing approximately 1 million metric tons of fertilizer per year in Nigeria by 1990.

The study was completed during March 1980, and a review of the report was held with a representative of the Nigeria Ministry of Industries. The report was then printed, and in May a presentation was made at Lagos, Nigeria, to representatives from the Ministries of Agriculture, Commerce, Industries, Planning, and Transportation. A resolution was drafted by the review committee and sent to the Executive Council recommending the adoption and implementation of the marketing system as given in the study.

The recommended marketing system, when implemented, will be able to meet its target of marketing approximately 1 million metric tons of fertilizer per year in Nigeria by 1990.

The ASEAN study offers insight into the effects of different supply strategies upon the fertilizer economy of the countries and provides a guide to decision-makers for the future development of fertilizer supply sources for the region.

Asia

ASEAN REGIONAL FERTILIZER ECONOMY PLANNING STUDY

IFDC continued the update of the ASEAN regional fertilizer sector planning study, which investigates the economic implications of alternative fertilizer supply strategies for the ASEAN countries—Indonesia, Philippines, Malaysia, and Thailand. The initial study was conducted jointly by the World Bank and IFDC in 1975.

For the update, a dynamic model of the regional fertilizer sector was developed using linear programming. The first update was carried out in 1978 using data collected during 1977/78. The data were collected in collaboration with country representatives. A preliminary report was prepared, and discussions were held in each country. A further update began in 1979 with revised data and continued into 1980.

Four selected supply strategies were being considered, ranging from full regional cooperation to varying degrees of self-sufficiency in fertilizer supply by each country.

The study offers insight into the effects of different supply strategies upon the fertilizer economy of the countries and provides a guide to decisionmakers for the future development of fertilizer supply sources for the region. The updated study is being published by IFDC.

HANDLING OF IMPORTED BULK FERTILIZERS IN INDIA

IFDC is involved in assisting developing countries in improving their internal fertilizer distribution systems and in converting from bagged import to bulk import of fertilizer, with bagging performed in-country. This saves significantly in overall cost and in foreign exchange and provides considerable local employment.

India is importing about 5 million metric tons of fertilizer in bulk. Some of this fertilizer is handled by a government agency and some by private fertilizer companies. IFDC staff discussed with officials of the Ministry of Agriculture and the Fertiliser Association of India (FAI) the systems for handling imported bulk fertilizer and for inland movements by unit train. Visits were made to the major ports and to some of the smaller harbors to observe methods for handling and bagging of imported bulk fertilizers. The valuable information that was obtained is applicable to fertilizer handling in other developing countries and will also be used in IFDC training courses.

MALAYSIAN FPM SENDIRIAN BERHAD GRANULATION PROJECT

FPM Sendirian Berhad is a newly formed fertilizer production organization in Malaysia, with ownership shared by Federal Land Development Authority of Malaysia; the Malaysian Bank; Pertanian; and Behn, Meyer & Company. FPM is constructing a fertilizer granulation plant at the Johore Port in southern Malaysia. The plant is designed to produce urea-based granular compound fertilizers (nitrogen-phosphate-potassium) specifically tailored for aerial application on oil palm and rubber estates.

In 1979 IFDC conducted pilot-plant studies and developed a process design for the production of these urea-based fertilizers. A key objective of the work was to produce products having suitable physical and chemical properties for the intended use. Several of the products were successfully tested under actual use conditions in Malaysia to demonstrate their suitability. The process and product development work was performed on a contract basis for Behn, Meyer & Company.

During 1980 IFDC continued to serve as technical consultant to FPM and to the engineering company selected by FPM. The plant is expected to be ready for commercial operation in mid-1982.

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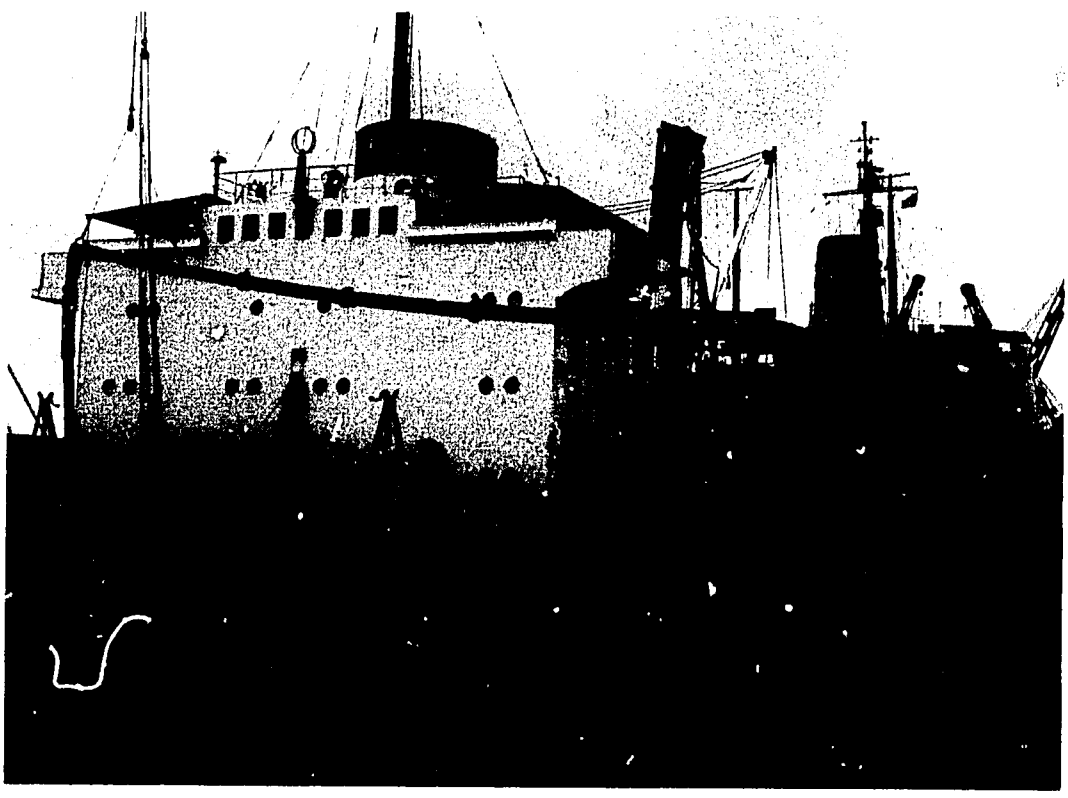
THAILAND STRATEGY FOR FERTILIZER DEVELOPMENT

In 1979 IFDC prepared a report entitled "Thailand—Strategy for Fertilizer Development," based on a study carried out in association with the World Bank and Thailand's National Committee on Fertilizer and Pesticide Industry Development (NCFPID). In 1980 at the request of and with assistance from the



This ship is being unloaded at a dock adjacent to the FPM plant site at Johore Port in Malaysia.

Latin America

World Bank, the summary section of the comprehensive report was updated and issued as a separate report to the World Bank and NCFPID for use in sectoral development planning. This summary report was subsequently published by IFDC as an executive brief under the title, *Thailand—Strategy for Fertilizer Development, A Prefeasibility Study.*

Progress was made in planning the development of Thailand's fertilizer sector based on use of indigenous supplies of natural gas to produce ammonia and other downstream products as discussed in the IFDC/World Bank strategy study. A large number of fertilizer project proposals were received in response to an invitation to bid on the establishment of such a project issued in mid-1980 by the Thai Ministry of Industry. Discussions were also held between the Thai Government and fertilizer industry representatives relative to the possible development of Thailand's potash resources, a topic also covered in the above-noted strategy study.

FERTILIZER SUPPLY STUDY FOR EAST CARIBBEAN COMMON MARKET (ECCM) COUNTRIES

IFDC, at the request of the Caribbean Development Bank (CDB), conducted a study for an alternative fertilizer supply scheme for the ECCM countries. The ECCM countries consist of the seven small states of the Windward Islands (Dominica, Grenada, St. Lucia, and St. Vincent) and Leeward Islands (Antigua, Montserrat, and St. Kitts/Nevis/Anguilla). The purpose of the study was to assist CDB in making an assessment of the feasibility of establishing a regional fertilizer production and supply center to serve the ECCM countries and possibly Barbados. The countries currently import bagged finished fertilizers from international market sources.

The constraints imposed on fertilizer supply schemes for the ECCM region limit the alternatives that may be viable options to the current scheme. No basic and intermediate raw materials are available in the region. Current fertilizer consumption is less than 25,000 metric tons per year and consists of a large variety of fertilizer products. Considering these constraints and that the countries are separated by sea, a bulk-blending and bagging facility based on imported bulk fertilizers has significant technical and economic advantages over other alternative supply schemes that might be considered. Accordingly, a technical and economic analysis of such a bulk-blending and bagging scheme was made and compared with the present supply scheme.

A conceptual design of a proposed bulk-blending and bagging facility was prepared and used as a basis for developing preliminary estimates of capital investment and production costs. A comparative economic analysis was made of the product cost estimates (landed cost basis at receiving ports) for bulk-blending and bagging versus importation of bagged finished products. The analysis indicates that a potential saving of US $15-$20/metric ton for the principal fertilizers can be realized. This preliminary study indicates that a centrally located bulk-blending and bagging project may be a technically and economically viable project for the ECCM region. In addition to the potential saving on product costs, the supply scheme offers improved product supply availability, greater flexibility in fertilizer material imports, and additional economic advantages for the region.

The study report included recommendations with respect to the planning, engineering and construction, and operational phases of the proposed bulk-blending and bagging facility project to enhance its technical and economic viability. To provide background information and premises for the supply study, the study and report included a review and assessment of the economy, agricultural sector, fertilizer use, and fertilizer marketing and distribution for the ECCM region and Barbados.

BRAZIL

Centro de Estudos de Fertilizantes (CEFER)

IFDC continued to provide technical assistance to CEFER, a state-owned fertilizer research and technical assistance center located in Sao Paulo, Brazil. CEFER, established in 1976, is one of 13 divisions that comprise the Instituto de Pesquisas Tecnologicas (IPT), which is also owned and operated by the State of Sao Paulo.

Since the inception of CEFER, the major objective of IFDC assistance has been to help CEFER assume its role as the major fertilizer research and development center of Brazil. This is done by training CEFER staff and helping them provide technical assistance to the fertilizer industry in Brazil. During 1980, 10 CEFER engineers and specialists visited IFDC for a total of 40 workweeks to obtain information and training designed to develop skills in (1) design and operation of granulation and phosphoric acid pilot plants, (2) fluid fertilizer technology, (3) maintenance management for fertilizer plants, (4) application of computer technology to least cost formulation of bulk-blended fertilizers, (5) fertilizer production and physical distribution systems, and (6) fertilizer marketing and distribution. This training was provided through informal discussions; on-the-job training at IFDC, TVA, and industrial plants; and attendance at formal IFDC training courses such as the Fertilizer Marketing and Distribution Program and the Maintenance Management Training for Fertilizer Producers course.

In addition to the training of CEFER staff at IFDC Headquarters, three short-courses on fertilizer production were held at CEFER Headquarters during 1980. The courses were developed and coordinated by IFDC. Instructors for the courses were recruited from IFDC, TVA, two U.S. commercial fertilizer producers, and one Brazilian fertilizer producer. The courses were designed to provide in-depth technical information, discussion, and training for CEFER staff and representatives of the Brazilian fertilizer industry. This program will continue through CY 1981.

Industrias Luchsinger Madorin, S.A. (ILM)

As a result of the two previous visits by two IFDC production engineers to ILM in 1979, an effluent/pollution assessment study of the Rio Grande, Brazil, production units was conducted to identify and measure the magnitude of the process losses and to develop recommendations for decreasing the level of pollution and losses.

To accomplish these goals a four-man team consisting of an IFDC chemical engineer and technician, an environmental engineer from Agrico Chemical Company (U.S.A.), and an environmental chemist from Texasgulf, Inc., (U.S.A.) visited the plant during May 1980 to assess the pollution characteristics, both actual and potential, of the major production units at the complex. The results of this assessment were used to determine the present efficiencies and to serve as a basis for recommending further studies, process equipment, and operating modifications.

With a large amount of technical input from IFDC, major emphasis is now being focused on methods to improve and optimize the production efficiency of ILM's granulation plant complex and related processing facilities.

Left—*Mr. S. K. Hoh (left) of Behn, Meyer Company and IFDC's Mr. Atticus Harrison, Pilot Plant Assistant, assist in pilot-plant trial production of urea-based NPK products for use in Malaysia.*

Right—*Mr. George W. Bolds (right), IFDC Production Specialist, works with ILM engineers and operators in Brazil to optimize production of NPK products containing large amounts of phosphate.*

ILM is establishing a pollution-monitoring branch and is training its own personnel through U.S. industry visits coordinated by IFDC. With a large amount of technical input from IFDC, major emphasis is now being focused on methods to improve and optimize the production efficiency of ILM's granulation plant complex and related processing facilities.

COLOMBIA FEASIBILITY STUDY FOR DEVELOPMENT OF PHOSPHATE ROCK DEPOSITS

In 1979 Empresa Colombiana de Minas (ECOMINAS), an agency of the Government of Colombia, engaged a consortium of four organizations including IFDC to perform a study to determine the feasibility of commercial exploitation of Colombia's Pesca and Sardinata phosphate rock deposits for fertilizer production and domestic consumption. The consortium included organizations having expertise in engineering and project management; geological exploration and mining; ore processing and beneficiation; and marketing, agronomy, and chemical processing (IFDC contribution).

In early 1980 IFDC completed the market survey portion of the study.

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These data were used to develop alternative production strategies for the utilization of the various grades of Pesca and Sardinata phosphate rocks identified as a result of the geological explorations. Large samples of processed and beneficiated phosphate ore were sent to IFDC for conversion into phosphoric acid and superphosphate. Laboratory and pilot-plant scale chemical processing

IFDC Pilot Plant Technician, Mr. David B. Wright, and ECOMINAS Chemical Engineer, Mr. Pedro Acosta, examine pilot-plant production of granular TSP made from Colombia's Pesca phosphate deposit.

studies began at IFDC in late 1980 and will continue in 1981. The chemical processing data will be the basis for developing process design and capital investment data, a major component of the feasibility study.

GUYANA LIME PROJECT

In late 1979 IFDC, in response to a request by USAID, prepared the terms of reference for a study for mining and processing beach shells for use as liming material in Guyana. The proposal was accepted by USAID and the Guyana Geology and Mines Ministry in 1980 and resulted in a visit by two IFDC staff members and two consultants who performed the site study and reported their findings to USAID.

The soils of Guyana's coastal plains are generally low in pH and calcium and may have an imbalance between calcium and magnesium. Liming is required for correction of both problems. Guyana has no deposits of limestone or other mineral calcareous materials. However, the beaches of the northwest district have large shell deposits with high calcium carbonate content. These shells have been used as liming material in small-scale tests for the past 20 to 30 years, but no major exploitation has resulted.

The study showed that while it is technically feasible to mine and use the shell beach materials as agricultural lime, mining and processing costs are quite high. Costs were compared with imported aragonite (a form of calcium carbonate now being used by Guyana Sugar Company and other plantations), which costs US $50/metric ton.

The method of recovery of shells deemed most feasible consists of removing the shells from the beaches, utilizing a hydraulic dredge, and transferring the shell slurry to barges for transport to a central processing area where the shells will be ground for subsequent use (Figure 14). The economic viability of this recovery method is dependent upon contracting for the dredging service instead of local capital expenditure for this operation.

PERU

Fertilizantes Sinteticos, S.A. (FERTISA)

FERTISA is engaged in a long-term planning strategy involving relocation of their nitrogen plant and production of new nitrogen products. During 1980 an IFDC engineer visited FERTISA to discuss and advise on the production plans and economics of this project.

The extent of the shell deposits is portrayed by the vast amount on the Almond Tree Beach in Guyana.

FERTISA now produces two types of ammonium nitrate—fertilizer grade and technical grade (for explosives). In the future they also would like to obtain government approval to produce a special type of ammonium nitrate for explosives, which is now imported. Ammonia would be imported initially and converted to nitric acid and ammonium nitrate with a long-term plan to produce ammonia at the new site. A large quantity of technical information was provided to FERTISA.

VENEZUELA FERTILIZER SUPPLY STRATEGY

In early 1980 IFDC was retained by Petroleos de Venezuela, S.A. (PDVSA), administrator of the nation's petroleum industry and its associated petrochemical and fertilizer production operations, to develop a fertilizer supply strategy to enable Venezuela to meet its domestic fertilizer needs in the 1981-90 decade. The study terms of reference as prepared by IFDC and PDVSA had three principal objectives: (1) to delineate the types and quantities of fertilizers required by Venezuelan agriculture, (2) to recommend least cost fertilizer supply alternatives, and (3) to recommend improvements in the marketing and distribution system to ensure cost-effective and timely delivery of fertilizers to the nation's farmers.

The study was carried out by a seven-member IFDC study team assisted by counterparts from PDVSA and its subsidiary, Petroquimica de Venezuela, S.A. (PEQUIVEN), the nation's sole fertilizer producer.

In early 1980 IFDC was retained by Petroleos de Venezuela, S.A. (PDVSA), to develop a fertilizer supply strategy to enable Venezuela to meet its domestic fertilizer needs in the 1981-90 decade.

The in-country data gathering phase of the study was carried out in June-July 1980. Data analysis, evaluation, and report preparation were carried out at IFDC Headquarters. A draft of the study report was submitted to PDVSA for review and comment in December 1980. The final report was presented to PDVSA/PEQUIVEN personnel in 1981.

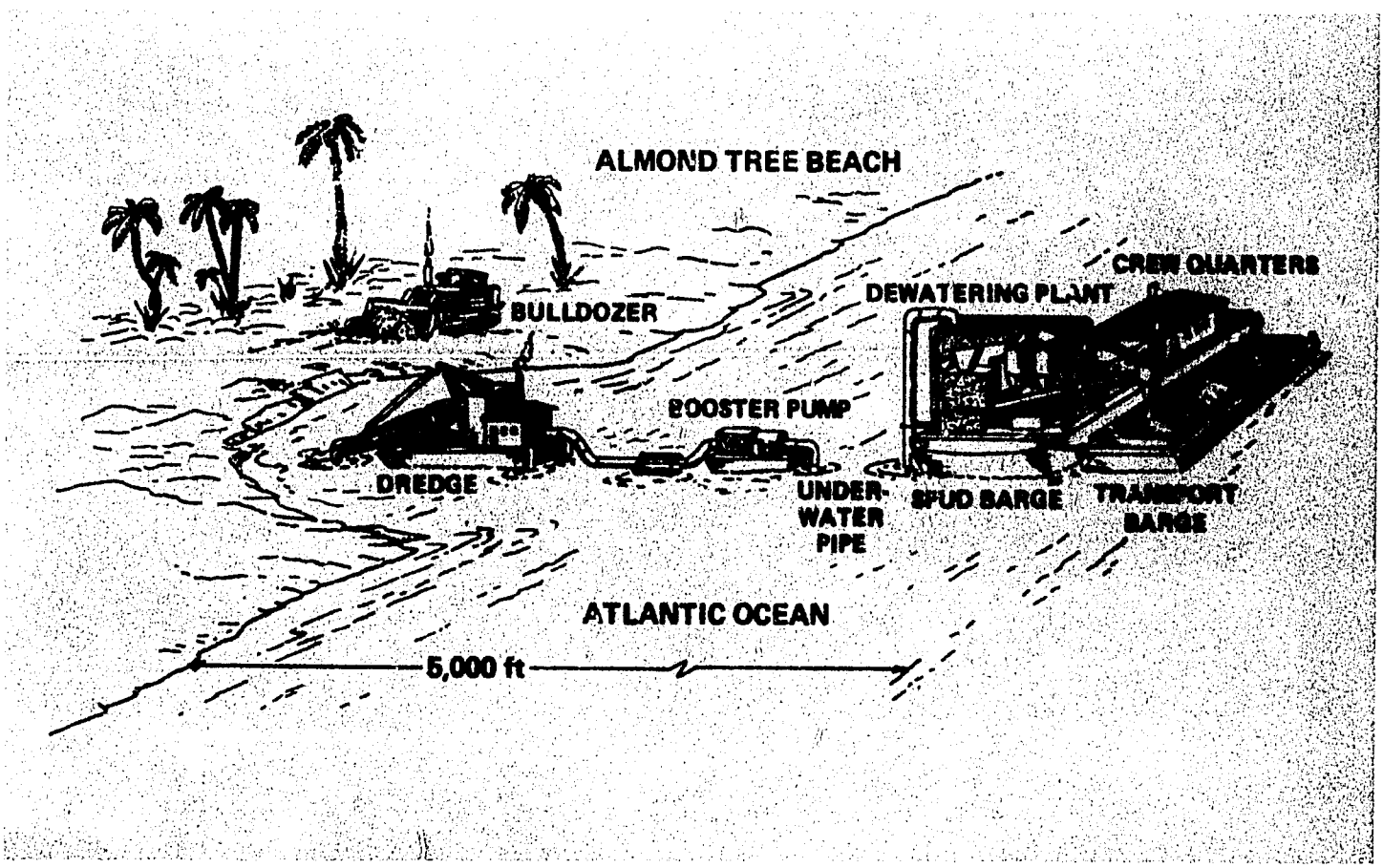
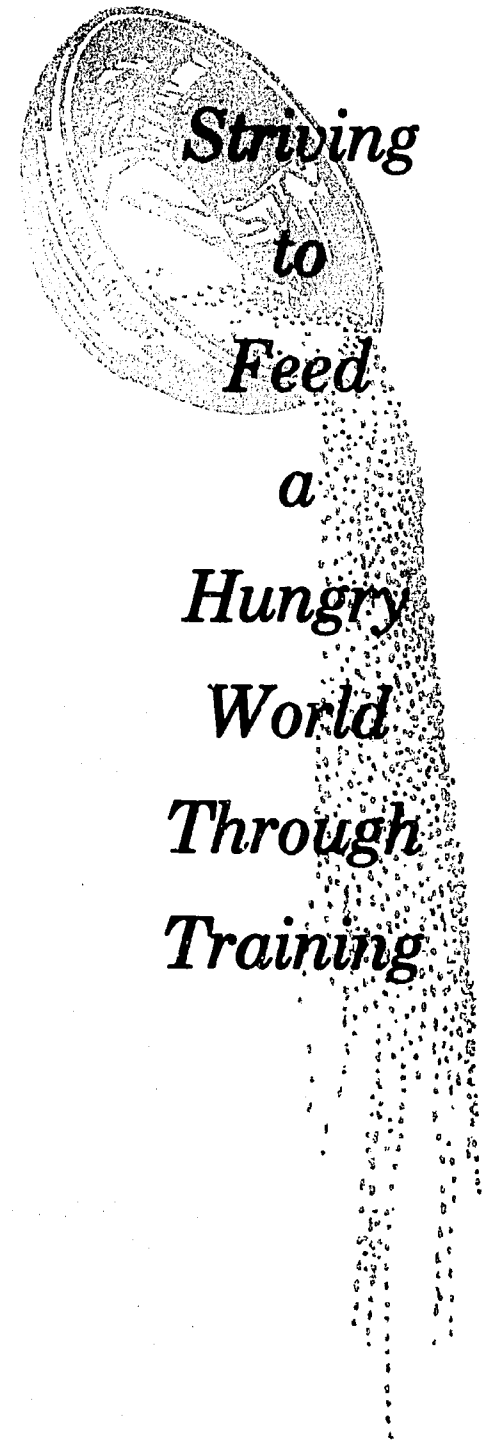


Figure 14. Guyana Shell Recovery Operation.

Training



A major and rapid increase of trained manpower must take place in the fertilizer sector of the developing countries if the world is to feed its people.

A major and rapid increase of trained manpower must take place in the fertilizer sector of the developing countries if the world is to feed its people. Most experts agree that at least 20,000 additional specialists must be added to the workforce each year in this sector if these countries are to meet their fertilizer targets. From its inception IFDC has recognized this need and has devoted a major portion of its resources to assist developing countries in meeting the manpower requirements of the fertilizer sector. A major grant from UNDP allowed IFDC to intensify this effort in 1980. As a result of this expansion and intensification of activities, the training objectives now include:

1. Increasing fertilizer production capabilities;
2. Improving fertilizer marketing systems; and
3. Upgrading research capabilities (both industrial and agricultural) so that new and/or improved products, systems, and practices will be available to serve the fertilizer sector.

During 1980 IFDC conducted seven group training programs with a total of 209 participants and 161 participant training months. Group training involves formalized classroom programs, practical exercises, and appropriate field experience. IFDC also provides training for individuals and groups. Individual training programs are designed for specific needs of individuals from fertilizer-sector organizations. The duration of this type of training ranges from several days to a year or more. During 1980, 17 individuals from 10 countries received individual training for a total of 35 training months.

Training activities are focused in three broad fertilizer subject areas—marketing, production, and fertilizer efficiency research. During 1980 six group training programs, two in each subject area, were held, utilizing UNDP funds (Table 3). In addition to these programs, a program funded by and designed to meet the needs of CEFER was conducted (see Technical Assistance section). An INSFFER training program also was conducted at IRRI (see Nitrogen Research section).

During 1980 IFDC conducted seven group training programs with a total of 209 participants and 161 participant training months.

Group Training

Table 3. 1980 UNDP-Funded IFDC Group Training Programs

Subject Area and Title	Location	Date	Cosponsor	Number of Participants	Participant Workmonths
FERTILIZER MARKETING					
Fourth Fertilizer Marketing and Distribution Program	IFDC Headquarters	August 11-September 19	None	39	58.5
Regional Fertilizer Marketing Training Program	India	November 17-December 3	FAI	31	25.5
FERTILIZER PRODUCTION					
Regional Granulation Seminar	Thailand	July 21-25	Ministry of Industries, Thailand	52	13
Maintenance Management Training	IFDC Headquarters	November 24-December 12	None	26	20
FERTILIZER EFFICIENCY RESEARCH					
Fertilizer Efficiency Research in the Tropics—FERITT I	Colombia	September 15-October 4	CIAT	26	19.5
Fertilizer Efficiency Research in the Tropics—FERITT II	Kenya	November 24-December 11	IITA	35	24

MARKETING

IFDC marketing programs deal with the identification of fertilizer needs of farmers and the functions and activities required to fulfill the identified needs.

The objectives of each of the two marketing programs conducted during 1980 were: (1) to raise the participants' levels of knowledge of fertilizer marketing from factory or port to end users; (2) to expose the participants to the latest marketing techniques; and (3) to demonstrate how to analyze, develop, adapt, or modify marketing systems to fit conditions in a participant's country.

Participants of the Marketing and Distribution Program, held at Headquarters, exchange viewpoints on constraints to fertilizer use.

Fertilizer Marketing and Distribution Program

The 1980 Fertilizer Marketing and Distribution Program was conducted at IFDC Headquarters during August 11 to September 19. Thirty-nine executives with managerial backgrounds and responsibility for fertilizer marketing in their countries participated in the program. Eight participants were from Indonesia; six from Bangladesh; five from India; three from Brazil; two each from Egypt, Pakistan, Sri Lanka, Tanzania, and Venezuela; and one each from Zaire, Philippines, Nigeria, Peru, Israel, Japan, and Malaysia.

The program included lectures, discussions, and multimedia presentations on: (1) the world fertilizer situation; (2) fertilizer production, industry, and economics; (3) marketing and distribution planning strategies; (4) factors affecting marketing planning; and (5) analysis and development of appropriate marketing systems. Experts from IFDC, TVA, the fertilizer industry, and universities served as discussion leaders.

A computerized fertilizer marketing simulation and leadership effectiveness training also were included. Each participant presented a country profile on his country with detailed information on fertilizer consumption and marketing.

Two field trips—one to the Corn Belt in the Midwest and another to Florida—formed an integral part of the program. The trip to the Corn Belt was centered in Kansas City and included visits to Farmland Training Institute, a fertilizer factory, a research farm, fertilizer dealers, and also to farms in the area. Participants met with the extension and teaching staff of the College of Agriculture, University of Missouri at Columbia, and visited the research and demonstration farm of the University. The trip to Florida included visits to International Minerals and Chemical phosphate rock mining operations and fertilizer manufacturing plants. Fertilizer handling at Tampa Port was also observed by the participants.

Regional Fertilizer Marketing Training Program in India

IFDC, in cosponsorship with FAI, conducted its first Regional Fertilizer Marketing Training Program during November 17 to December 3 in Bombay and New Delhi.

Thirty-one participants, representing 10 countries and 22 organizations, attended the program. All participants had fertilizer marketing supervisory responsibilities within their organizations or companies. Seven participants each were from Bangladesh and Indonesia; six from India; three each from Sri Lanka and Thailand; and one each from Burma, Jordan, Malaysia, Pakistan, and Saudi Arabia.

IFDC, in cosponsorship with FAI, conducted its first Regional Fertilizer Marketing Training Program during November 17 to December 3 in Bombay and New Delhi.

Twenty-two experts from IFDC, the Food and Agriculture Organization of the United Nations (FAO), and India led discussions on world and regional fertilizer demand, supply, and production technology and reviewed research on soils, crops, and fertilizer use that affect fertilizer consumption and fertilizer marketing systems in different countries of Asia. The program also covered such topics as estimating fertilizer demand, identification and removal of constraints to fertilizer use, fertilizer legislation, policies, promotion, credit and crop insurance, transportation, warehousing, handling, packaging, and marketing costs. The presentations consisted of lectures, case studies, and panel discussions and were supported by slides, transparencies, films, and charts.

Field trips formed an integral part of the program and provided a practical complement to the training sessions. In the Bombay area, the participants visited Trombay fertilizer complex of the Rashtriya Chemicals and Fertilizers, Ltd., granulation and superphosphate plants of Maharashtra Agro-Industries Development Corporation, and the port of Bombay where they saw fertilizer handling operations. The field trips around New Delhi consisted of visits to the Farmer Service Center of Indian Farmers Fertiliser Cooperative, Ltd. (IFFCO), the buffer storage facilities, and a retail distributor of Indian Explosives, Ltd., all located in Rohtak.

Participants also saw the farmers' field day organized by the Shriram Khad Program in the village of Badshahpur near New Delhi and the whole-farm and method demonstration of IFFCO in the village of Lali near Rohtak. The visits provided an opportunity for the participants to consult with marketing/promotion personnel of fertilizer companies, cooperative and government officials, dealers, and typical small farmers of Indian villages. Question-and-answer sessions involving the participants and the farmers showed the similarity of field problems in Asian countries.

PRODUCTION

IFDC production training programs include all elements of handling and processing raw materials into ready-to-use fertilizer products. Two programs were conducted in 1980—one was concerned with fertilizer granulation and one dealt with maintenance management.

Regional Fertilizer Granulation Seminar for Asia

IFDC conducted this seminar with the Ministry of Industry of Thailand as cohost in Bangkok, July 21 to 25. Fifty-two participants representing nine countries and 29 organizations attended. The seminar was concerned with the production of multinutrient granular materials and the unique problems facing this industry. This seminar was the first in a series on granulation and bulk blending and was scheduled for Asia because of recent inquiries from that area on the subject of fertilizer granulation.

The objective of the program was to provide the participants with a broad overview of fertilizer granulation technology with emphasis on processes and operating techniques suitable for tropical regions. Fundamentals of plant management and organization, inventory control, quality control, and environmental protection were covered.

The program was geared toward fertilizer plant managers, production managers and supervisors, and others with production responsibility or involvement. The principal method of presentation was lectures supported by visuals and one field trip, hosted by the Thai Central Chemical Company (TCCC). Each participant received a "mini-library" of materials that included lecture transcripts, background materials, books, and technical literature related to the seminar topics.

This seminar was the first in a series on granulation and bulk blending and was scheduled for Asia because of recent inquiries from that area on the subject of fertilizer granulation.

Maintenance Management for Fertilizer Producers

This course was conducted at IFDC Headquarters during November 24 to December 12. Twenty-six participants from 11 countries attended. The course was designed for plant managers, maintenance superintendents, scheduling and procurement engineers, and first-line maintenance supervisors from the fertilizer sector of the developing world.

Objectives of the course were: (1) to provide participants with instruction on the theoretical and practical aspects of organizing and managing an effective maintenance program; (2) to identify and relate maintenance planning and execution to the realization of factory production goals; and (3) to illustrate the basic techniques and methods used to plan, schedule, and implement maintenance tasks.

Most of the course material was presented in a classroom-workshop

Upper Right—*Mr. J. J. Schultz, IFDC Technical Training Assistance Coordinator, makes a point during a discussion period at the Bangkok seminar.*

Right—*Participants register at the Regional Fertilizer Granulation Seminar in Bangkok, Thailand. Fifty-two participants from 29 organizations attended.*

Extreme Right— *FERITT course participants develop techniques for fertilizer evaluation using greenhouse facilities at CIAT in Colombia.*

environment by a faculty of IFDC experts and two maintenance management consultants. During the last week of the course, the classroom material and training were reinforced by two 3-day orientation and demonstration-type seminars hosted by two large commercial fertilizer producers located on the Gulf Coast of the United States. This exposure to the industrial sector gave the participants an opportunity to observe and discuss firsthand the techniques and methodology used by successful fertilizer producers to implement an effective maintenance management system.

Each participant was given a complete set of the course technical papers and books to be used for further self-study and the teaching of others.

USE

Fertilizer Efficiency Research in the Tropics Training Program

IFDC fertilizer efficiency research training programs include the basic techniques for evaluating and determining proper use of currently available and improved fertilizer products and practices in tropical countries. Through these programs, IFDC intends to develop technical capability in field research on fertilizer efficiency using standard comparison methods and statistical analysis suitable for computer programming.

The program's goal 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.

One-half of the time spent in the Fertilizer Efficiency Research in the Tropics (FERITT) program is devoted to classroom instruction and the other half to practical laboratory, greenhouse, and field exercises. Procedures for conducting fertilizer trials with new or improved fertilizer materials; application techniques; and agronomic, economic, and statistical analysis of results are emphasized. The participants take an active part in the design, planting, harvesting, measuring, and data development of standard field experimental procedures. A final report is written that emphasizes recommendations based on economic calculations and

Training Evaluation

yield response. The complete operation from planting to harvest is made possible by the cooperation of the cosponsor in planting an identical field experiment with enough lead time to allow the crops to mature while the course is in session.

One FERITT program was held in cooperation with CIAT at Cali, Colombia, during September 15 to October 4. The program was conducted in Spanish for 26 agronomists from 12 Latin American countries.

The other FERITT training program was held in cooperation with the International Institute of Tropical Agriculture (IITA) and the University of Nairobi in Nairobi, Kenya, during November 24 to December 11. Thirty-five agronomists from 16 countries attended.

A formal evaluation was made of each of the six IFDC group training programs conducted during 1980. Emphasis was placed on measuring each participant's level of knowledge of a program's technical subject matter both at the beginning and at the end of the training program. Additionally, evaluation data collected during each program were analyzed to identify participant perceptions of the adequacy of program speakers and audiovisual aids, importance of topics covered, relevance and novelty of information presented, level of treatment of program topics, and time allowed for speaker presentations and participant discussion.

The precourse evaluation data indicated that many participants entering IFDC's training programs had relatively low levels of knowledge of the technical subject matter covered in these programs. For example, in both the IFDC-based and regional fertilizer marketing training programs, the level of participant knowledge of technical subject matter was generally lower in the fertilizer-specific than in marketing-specific areas. Comparison of overall group scores from these two programs also revealed that technical knowledge levels, both at the beginning and end of each program, were lower among participants in the regional group. These differences reflect personal, organizational, and regional variations in the background of the specific audiences for which each program is targeted. Such differences further reconfirm the great

FERITT participants lay out field plots in Kenya during a practical exercise in plot design. This course was held in cooperation with IITA and the University of Nairobi.

need for training programs of the type offered by IFDC to include both strengthening of technical expertise and developing of problem identification and decisionmaking skills at various management levels in the fertilizer marketing systems of developing countries.

A formal evaluation was made of each of the six IFDC group training programs conducted during 1980. Emphasis was placed on measuring each participant's level of knowledge of a program's technical subject matter . . . .

Participant evaluations have provided valuable feedback that has served to improve the content, organization, and impact of each program. Specific areas being improved in IFDC training programs as a result of the training evaluation program include:

1. Structuring the program content to maintain a balance of overview, technical update, and applied components; the latter area includes case studies, IFDC's computer-assisted Alpha fertilizer marketing decision simulation, laboratory and fieldwork, and workshop participation;
2. Sequencing the training activities to provide continuity and reinforce learning;
3. Developing lecture presentations and, where appropriate, high-quality training modules that can be used repeatedly;
4. Synchronizing the technical and organizational inputs to the planning, execution, evaluation, and followup of IFDC's training programs;
5. Providing feedback to counterpart organizations participating in IFDC training programs at the regional and country level.

Financial Report

Price Waterhouse & Co.

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

March 12, 1981

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 functional expenses present fairly the financial position of International Fertilizer Development Center (IFDC) at December 31, 1980 and 1979, and the results of its operations and changes in 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 & Co.

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

CURRENT FUND (unrestricted)

ASSETS

	December 31, 1980	December 31, 1979
Cash	$ 384,481	$ 865,523
Certificates of deposit	1,475,141	607,943
Short-term investments (Note 1)		210,000
Amounts receivable from donors (Notes 1 and 2)	3,960,181	4,469,329
Other accounts receivable	478,549	616,609
Advances to employees	42,337	33,116
Supplies inventory (Note 1)	97,177	61,418
Prepaid expenses	31,836	27,955
	$6,469,702	$6,891,893

LIABILITIES AND FUND BALANCES

	December 31, 1980	December 31, 1979
Accounts payable	$ 277,429	$ 429,657
Accrued annual and sick leave	698,680	499,554
Deferred revenue (Notes 1 and 2)	3,960,181	4,469,329
Total liabilities and deferred revenue	4,936,290	5,398,540
Fund balance	1,533,412	1,493,353
	$6,469,702	$6,891,893

PROPERTY AND EQUIPMENT FUND (NOTE 1)

Buildings	$5,605,640	$5,605,640
Equipment	3,934,341	3,524,900
Construction in progress	57,855	
Less - Accumulated depreciation	(1,691,739)	(1,127,991)
	$7,906,097	$8,002,549

Accounts payable	$ 34,860	$ 9,904
Contract retainage	21,121	21,121
Total liabilities	55,981	31,025
Fund balance	7,850,116	7,971,524
	$7,906,097	$8,002,549

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENT OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

YEAR ENDED DECEMBER 31, 1980 WITH COMPARATIVE TOTALS FOR 1979

	1980		Total All Funds	
	Current Fund	Property and Equipment Fund	1980	1979
Revenue:				
Grants received (Note 2)	$5,296,198		$5,296,198	$5,648,525
Recovered project costs	1,689,573		1,689,573	1,493,468
Other	149,214	$ 1,500	150,714	32,707
Total revenue	7,134,985	1,500	7,136,485	7,174,700
Expenses:				
Research	3,756,566	451,015	4,207,581	3,386,223
Outreach	1,504,731	43,650	1,548,381	1,448,783
General and administrative	1,389,314	72,558	1,461,872	1,212,025
Total expenses	6,650,611	567,223	7,217,834	6,047,031
Excess (deficiency) of revenue over expenses	484,374	(565,723)	($ 81,349)	$1,127,669
Other changes in fund balances:				
Property and equipment acquisitions from unrestricted funds	(444,315)	444,315		
Fund balances, beginning of period	1,493,353	7,971,524		
Fund balances, end of period	$1,533,412	$7,850,116		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENT OF FUNCTIONAL EXPENSES

YEAR ENDED DECEMBER 31, 1980 WITH COMPARATIVE TOTALS FOR 1979

	1980			Total Expenses	
	Research	Outreach	General and Administrative	1980	1979
Personnel compensation (Note 3)	$1,987,634	$ 750,207	$ 761,951	$3,499,792	$2,951,087
Personnel benefits (Note 3)	270,701	131,418	121,644	523,763	454,328
Travel and transportation	300,065	270,990	77,932	648,987	560,504
Occupancy	211,359	70,721	69,803	351,883	282,940
Telephone and telegraph	66,355	31,796	20,463	118,614	60,911
Rental of equipment	18,196	12,181	6,852	37,229	93,638
Contractual research and development	133,017	137,531		270,548	125,199
Other contractual services	366,967	32,034	98,501	497,502	338,452
Institute of International Education fee (Note 3)			101,480	101,480	64,400
Materials and supplies	392,369	64,055	78,661	535,085	525,941
Postage	9,903	3,798	5,232	18,933	11,506
Insurance			46,795	46,795	36,449
Miscellaneous	560			560	162
Total expenses before depreciation and amortization	$3,757,126	$1,504,731	1,389,314	6,651,171	5,505,517
Depreciation of furniture and equipment and amortization of leasehold improvements	450,455	43,650	72,558	566,663	541,514
Total expenses	$4,207,581	$1,548,381	$1,461,872	$7,217,834	$6,047,031

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

NOTES TO THE FINANCIAL STATEMENTS

NOTE 1 - ORGANIZATION AND ACCOUNTING POLICIES:-

The 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 following is a summary of significant accounting policies:

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

B. Revenue and expenses are accounted for on an accrual basis. Grants are recorded as receivable for the full amount at the date of the grant. Amounts not clearly designated for a specified program period are deferred in the balance sheet and reflected in revenue when received. 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. Short-term investments are stated at cost, which approximates market.

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

NOTE 2 - GRANTS:-

Grants received are summarized as follows:

	Year ended December 31,	
	1980	1979
United States Agency for International Development (AID)	$4,000,000	$4,000,000
United Nations Development Programme (UNDP)		2,635,000
International Development Research Centre (IDRC)	558,125	328,956
Rockefeller Foundation	66,550	
Israel Chemicals Ltd.	25,000	50,000
Australian Development Assistance Bureau (ADAB)	137,375	
	4,787,050	7,013,956
Amounts deferred during prior year	4,469,329	3,103,898
	9,256,379	10,117,854
Less - Amounts deferred to future periods	(3,960,181)	(4,469,329)
Revenue recognized in current period	$5,296,198	$ 5,648,525

The current grant from AID was amended to provide additional funds of $4,000,000 during each of the years ended December 31, 1980 and 1979, and to extend the grant period from June 30, 1980 to June 30, 1981. The amounts of $1,900,000 and $1,900,000 had not been received at December 31, 1980 and 1979, respectively, and were not clearly designated for a specified program period and, accordingly, were deferred. The current amendment to the grant provides funds for basic core/operating costs. The use of funds by area is unrestricted except that equipment purchases may not exceed $3,022,000. Funds not legally committed at the grant expiration date will revert to AID.

The amount of $32,367 from the Rockefeller Foundation grant, the amount of $523,306 from the International Development Research Centre grant and the amount of $1,504,508 from the United Nations Development Programme grant were deferred at December 31, 1980.

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 quarterly to fund salaries, employment taxes and fringe benefits.

Staff

Office of the Managing Director

Donald L. McCune, Managing Director
Paul J. Stangel, Deputy Managing Director
Marjorie R. Engel, Administrative Director
Kathryn S. Adams, Word Processing Specialist
John H. Allgood, Budget Officer
Kaye F. Barker, Accountant
Diane S. Baskins, Clerk
Jacqueline A. Berrens, Clerk (Purchasing)
Roe W. Borden, Student Worker*
Betty F. Canerday, Mail Clerk
Glenda Carter, Accounting Clerk
Linda B. Cornatzer, Word Processing Specialist
Sylvia S. Flora, Graphics Assistant
Debra R. Garrett, Executive Secretary
Janice C. Gautney, Word Processing Specialist
Jane L. Goss, Word Processing Specialist
Alicia K. Hall, Word Processing Specialist
Travis P. Hignett, Special Consultant to the Managing Director
Barbara J. Holder, Communications Specialist
Vickie Jane Hollandsworth, Clerk-Typist
W. Diane Kasmeier, Clerk (Purchasing)
James M. Kelly, Purchasing Agent
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Uday Mohan, Communications Trainee
Cheryl A. Moss, Illustrator
Sidney Painter, Personnel Officer
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Flora M. Rudolph, Technical Illustrator
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Parminder Singh, Visitor Relations Officer
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Jacqueline Ashby, Postdoctoral Fellow
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John T. Moraghan, Soil Scientist
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Adolfo Martinez, Fertilizer Use Economist
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Lewis B. Williams, Regional Coordinator—Africa

As of December 31, 1980
*Left during 1980

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