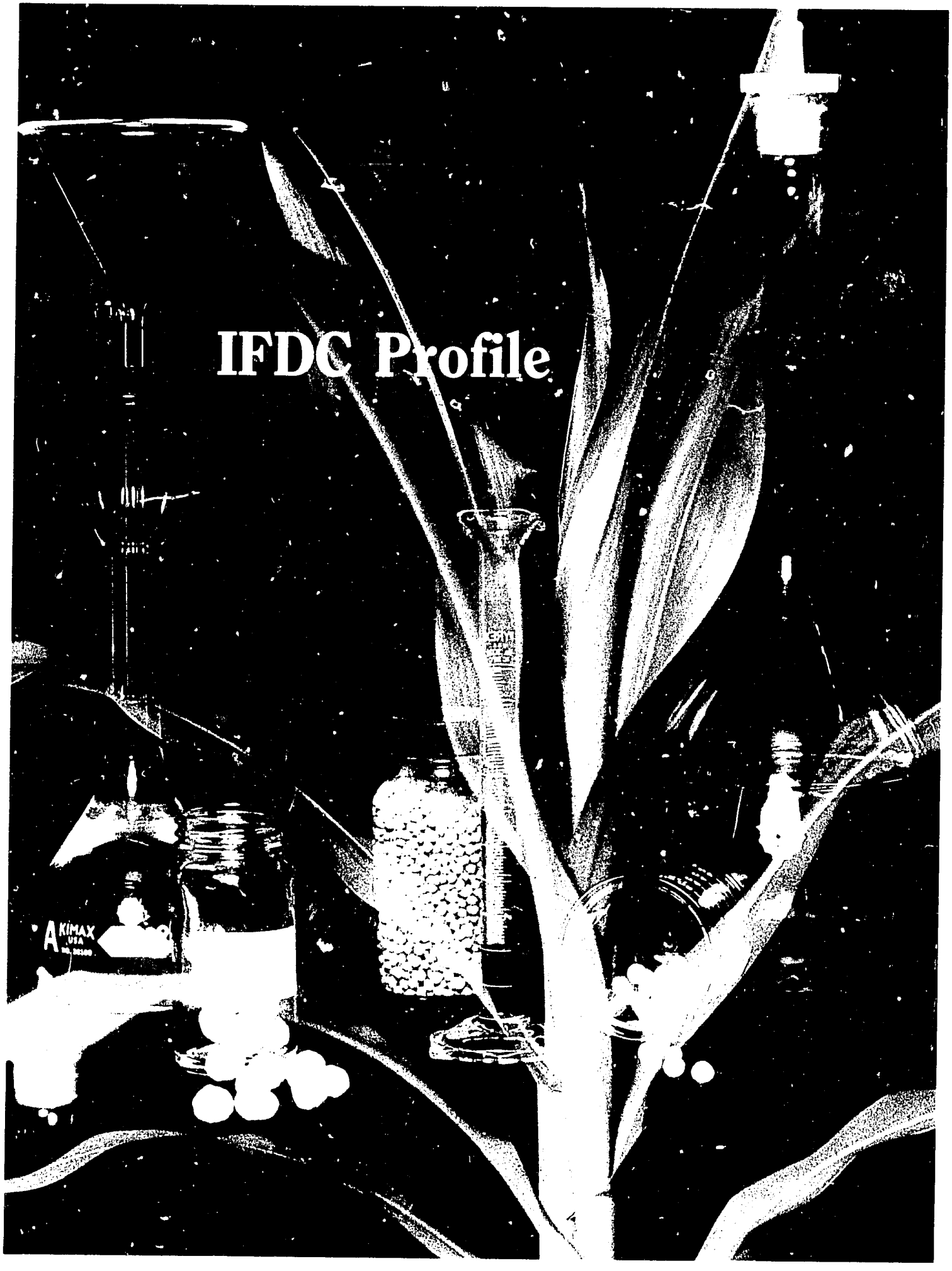
International Fertilizer Development Center
Annual Report, 1988

"Secu[illegible] Sustai[illegible]e Agriculture
[illegible] Dev[illegible]oping Countries"

IFDC Profile



International Fertilizer Development Center: Questions & Answers

How did the Center originate? What is its mission?

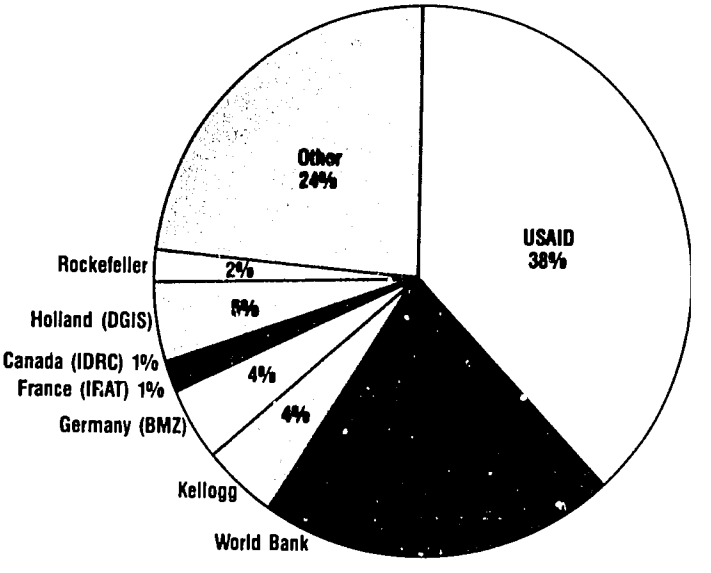
The world food crisis of the early 1970s provided the impetus for the creation of an international fertilizer research center to focus on the development of appropriate fertilizer technology and related knowledge to increase food production in the developing countries, especially those of the tropics 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. 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.

How is the Center funded?

Planning funds to establish IFDC came from the United States Agency for International Development (USAID) and the International Development Research Centre (IDRC) of Canada. In addition to the continuing support of these two organizations, funds for training, technical assistance, and research and development come from a wide range of national and international agencies, private foundations, and national governments. Some other donors of IFDC now include the Kellogg Foundation; Rockefeller Foundation; the World Bank; Directoraat Generaal voor Internationale Samenwerking (DGIS), the Netherlands; Der Bundesminister für Wirtschaftliche Zusammenarbeit (BMZ), F.R. Germany; Research Institute for Tropical Agriculture (IRAT), France; and the United Nations Development Programme (UNDP).

Photo: This Nigerien farmer harvests a millet crop. Because of the urgency of Africa's situation, IFDC has placed an increasingly greater emphasis on helping the people of that continent push their agriculture forward.

IFDC Funding Sources, 1988



Where is the Center located?

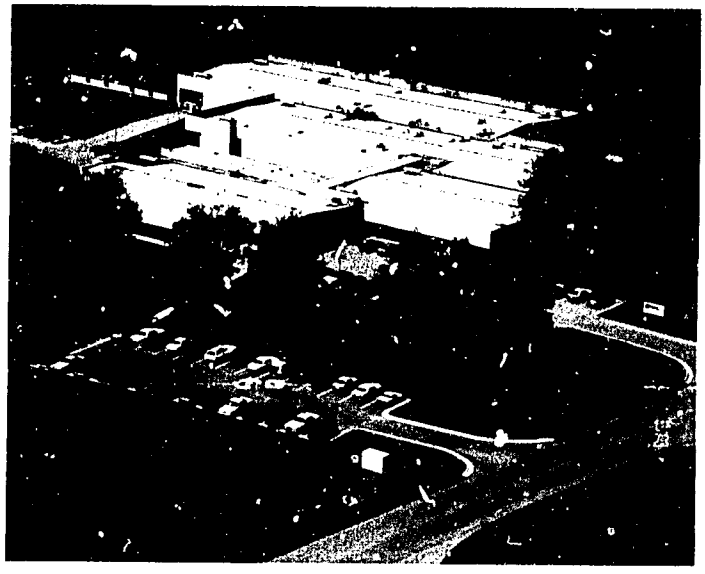
The Headquarters of IFDC is located in Muscle Shoals, Alabama. Its proximity to the Tennessee Valley Authority's (TVA) National Fertilizer Development Center (NFDC) facilitates a sharing of research information and a comprehensive fertilizer research library. With assistance from the Government of Togo, in 1987 IFDC established a regional base in West Africa to provide onsite attention to the special problems of the fertilizer sectors of the sub-Saharan countries of West Africa.

How is its Board of Directors constituted?

Program directions are shaped by a Board of Directors that is fully international and was established in accordance with standards set by the Consultative Group on International Agricultural Research (CGIAR). The members of the Board bring together a wide range of fertilizer expertise. The IFDC Board is composed of seven members from developing countries, three from the United States, and four from other developed countries.

Why is IFDC unique?

Because it is composed of an international, multidisciplinary, multilingual staff, IFDC can provide an unbiased opinion regarding most facets of fertilizer sector development. The IFDC staff, recruited from more than 20 countries, is both internationally and technically diverse with almost one-half of the total being chemical engineers, chemists, economists, agronomists, geologists, soil scientists, marketing specialists, and sociologists. IFDC is able to conduct unique fertilizer research and development because of three complementary factors: (1) the multidisciplinary structure of its task teams used for project planning and implementation; (2) the ability to produce and test experimental fertilizers in laboratories, pilot plants, greenhouses, and experiment stations and fields in the developing countries; and (3) linkages with research and development institutions around the world. IFDC's professionals have participated in a wide range of projects in collaboration with national/international food and agricultural organizations; financial institutions; agricultural research stations; manufacturers and associations; and research and development agencies.



Above: IFDC Headquarters, located in Muscle Shoals, Alabama, serves as the hub of activity for research, technical assistance, and training programs conducted around the globe.

Below: The IFDC regional center operates from these rented facilities in Lomé, Togo. Through this regional base, IFDC is having a greater impact on West African agriculture.

How is it structured?

The three primary divisions of IFDC Headquarters are Agro-Economic, Fertilizer Technology, and Outreach. The Office of Managing Director is the administrative section of IFDC. The Agro-Economic and Fertilizer Technology Divisions are research oriented and focus on the development of products and practices to solve immediate and long-term problems. The Outreach Division is responsible for technology transfer through technical assistance and training, identification of problems of regional and global importance, conduct of fertilizer sector studies, and national field programs of an adaptive research nature. (The programs of the IFDC regional center, located in Lomé, Togo, are discussed in a later section.)

What about its facilities?

The Center's facilities include laboratories; greenhouses; growth chambers; specialized instruments essential for laboratory research; bench-scale and pilot plant units used in studies such as beneficiation of ores, acidulation, and granulation of fertilizers; and a word processing center, library, and communications unit, which are capable of disseminating information through various media.

Above: Carol Cole, IFDC Chemical Laboratory Analyst, and Dr. Dennis Friesen, IFDC Soil Scientist, conduct sulfur experiments in a Headquarters' laboratory. New fertilizer products are first screened for their effectiveness in Headquarters' laboratories.

Below: Dr. D. P. Verma, an ICRISAT Soil Scientist/Soil Chemist conducting collaborative research with IFDC in India, inspects a greenhouse experiment at IFDC Headquarters. Fertilizer products and practices developed at IFDC are tested in our greenhouses before being verified on fields in developing countries.

What about the Center's programs?

The endeavors of IFDC are conducted along four broad areas of research, national programs, technical assistance, and training.

Research—Major focus has been on developing solutions to problems related to nitrogen, phosphate, sulfur, potassium, calcium, magnesium, and micronutrients.

Training—Recognizing that people are the most valuable resource to be developed as part of the solution to the food production puzzle, IFDC has more than tripled the number of its training offerings since 1979. Since its inception the Center has provided training for people from more than 100 countries.

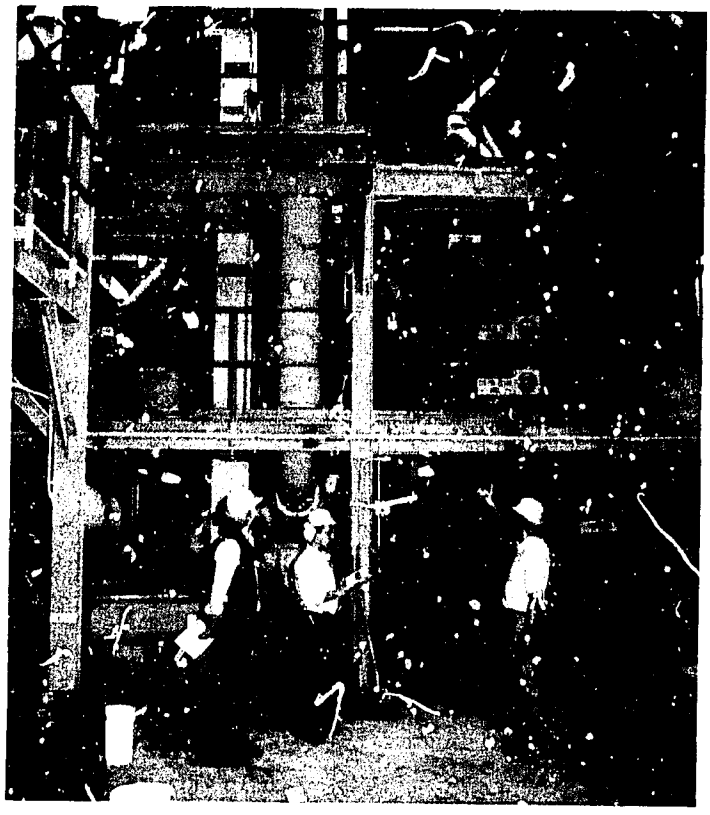
Technical Assistance—Technical assistance is another means that IFDC uses to transfer technology to developing countries. Since its inception the Center has provided technical assistance through a problem-solving approach to more than 80 countries.

National Programs—National programs provide a vehicle through which problems can be identified and technology can be screened and evaluated as to its applicability to specific agroecological and socioeconomic conditions of the developing countries. IFDC is now conducting such programs in Bangladesh and Indonesia.

The Programs of IFDC's Regional Center in Togo, West Africa—Focusing on the special needs of the sub-Saharan countries of West Africa, IFDC's Togo office has organized programs in the following areas: fertilizer information dissemination and technology transfer; fertilizer policy research; agronomic research; fertilizer investment for soil fertility restoration; indigenous agromineral research and development; monitoring, collection, and dissemination of fertilizer market information; and regional collaboration and training.

What are IFDC's linkages?

To help carry out its mission, IFDC cooperates with many international, regional, and national institutions, with 28 staff specialists currently outposted in Asia, Africa, and Latin America. Technology developed by IFDC scientists and engineers is tested under a wide range of conditions before its applicability is established for specific areas.



Above: In the IFDC Headquarters' Pilot Plant, new fertilizer products are developed in collaboration with engineers, soil scientists, and economists.

Below: IFDC/CIAT researchers harvest a rice experiment designed to test ^{15}N and plastic-coated urea. This work is just one phase of the IFDC/CIAT connection, which has tested the validity of new concepts in fertilizer technology on experiment stations prior to being transferred to farmers' fields.

Securing Sustainable Agriculture in The Developing Countries

Developing-Country Scene

Many developing-country landscapes are scarred and ruined by deforestation, desertification, and erosion. This phenomenon results from poverty that forces many farmers to take more from the earth than they can return. Thus, nothing is left to enrich the soil. Nothing is left to anchor the soil since the forest is used for building materials, fuel, and other purposes. The rains, when they do come, wash away precious topsoil. As a result, a poor soil yields a poor crop, and the cycle of poverty continues.

The prospects of Africa's future generations depend on decisions now being made and implemented by their countries' leaders. The development of efficient and effective fertilizer sectors can have a tremendous impact by helping to reverse the cycle of poverty.

Timeless Questions

The age-old questions are now being asked but with a greater sense of urgency than in the past. Can a better balance be struck between man and nature? Can the downward spiral of poverty leading to land degradation be unwound? Can the earth's natural resource base match the growing demands being hurled at it? Can developing nations find ways to adequately feed their growing populations, which are now predicted to comprise 90% of the expected world increase by the year 2000?

Fertilizer's Crucial Role

Ironically, for many of the developing countries, part of the answer to their dilemma lies hidden deep beneath the earth itself. The cruel cycle can be broken by taking from the earth natural resources, such as agrominerals—phosphate rock, sulfur, and potash—to produce fertilizers and then returning these valuable nutrients to the earth to replenish and restore the fertility of the soil and thereby make it more productive.

Thus, the basis for achieving sustainable agriculture is the soil itself, which contains the nutrients and stores water that is essential for plant growth. Large quantities of nutrients are lost through soil erosion, and harvested crops mine the nutrients from the soil unless they are continually replaced. Dr. John W. Mellor of the International Food and Policy Research Institute (IFPRI) has stated that to overcome their dilemma, developing-country farmers must "increase fertilizer use on the lowland areas, which boosts productivity and helps prevent cultivation on the hillsides."

In many tropical and subtropical countries, the amount of land that can be brought into cultivation is limited. Those areas that can be used for growing crops need organic and inorganic fertilizers to maintain

Bangladeshi field workers transplant rice. As a result of their country's recognition of the importance of instituting sound fertilizer policies, they are reaping the rewards in increased crop yields.

their yield potential because the soils of most of these areas are so infertile. Furthermore, high-yielding varieties are fertilizer intensive, and without adequate soil fertility they often produce lower yields than traditional varieties. It is generally agreed that high-yielding varieties were the stimulus for the Green Revolution, but it is also true that fertilizers fueled that engine of growth. In his Francis New Memorial Lecture to the Fertiliser Society of London in 1981, Dr. Donald L. McCune, IFDC's first Managing Director, cited a study by the International Rice Research Institute (IRRI), which showed that fertilizers accounted for at least 50% of the yield increases achieved during the Green Revolution.

Moreover, the increased use of fertilizers plays an important role in generating employment and income in rural areas and in saving and earning foreign exchange at the national level. Increased fertilizer use allows many developing countries to use their indigenous resources such as phosphate rock, coal, and natural gas in fertilizer production for domestic purposes and exports.

Compared with the fertilizer use in developed countries, its use per hectare of arable land in many developing countries is very low. In fact, sub-Saharan Africa uses only about 7 kg/ha of fertilizer; Latin America uses 32 kg/ha; and Asia uses 81 kg/ha (about the world average). Because of such low use levels, there is great potential for the developing countries to increase food production and improve the environment through the effective and efficient use of fertilizer.

Deforestation, desertification, salinization, and soil erosion represent serious environmental problems in many developing countries, especially in Africa and Latin America. The increased use of fertilizer in conjunction with other complementary inputs can assist in solving environmental problems by raising the productivity of cultivable land and thereby reducing pressures on marginal lands that are susceptible to desertification and soil erosion. Fertilizer can also help protect forests because the increased production from cultivable land will reduce the need to clear forests for cultivation. There are no cost-effective and socially acceptable technologies to universally build or maintain soil fertility without the use of inorganic fertilizer.

The reduction or elimination of fertilizer use would result in increased environmental degradation through deforestation, soil erosion, and desertification, as evidenced in recent years in sub-Saharan Africa. In many agricultural regions of developing countries, the real benefits of fertilizer use to the environment significantly outweigh any of the real or imagined detrimental effects.

Increased fertilizer use by African farmers can help to place more food on their tables. This Nigerien girl holds a bowl of ground millet, which will be used to feed her family.

IFDC: At the Heart of the Solution

We at IFDC believe that sustainable, environmentally safe agriculture can become a reality, provided the necessary policies, strategies and programs are put in place to increase food production in the developing countries. Sustainable agriculture, according to the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research, should involve the "successful management of resources for agriculture to satisfy the changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources."

The work of IFDC over the past 14 years dovetails perfectly with the specifications of the TAC Secretariat's definition. The Center has maintained a sustainable perspective in its approach before it was considered essential to long-term agricultural development. Its focus on long-term solutions to food production problems clearly satisfies the requirement that sustainable agriculture provide for the changing needs of people. Since 1975 IFDC's scientists have been striving to create a more sustainable agriculture in the developing countries by helping them to use their own raw materials to produce the necessary fertilizers needed to build soil fertility and produce more food. We have joined forces with national collaborators to develop the human capital needed to effectively and efficiently carry out the many functions of the fertilizer sector. We have always stressed the need for efficiency in the production, marketing, and use of fertilizer to ensure its cost-effectiveness. The synergistic partnerships that we have developed with scientists, policymakers, and extension leaders of developing countries have helped to keep the Center's technology responsive to the changing needs of developing-country people. We realize that we must test and mold our technology to fit the socioeconomic, cultural, and ecological conditions of the developing countries where it is designed to be used.

This young Bangladeshi entrepreneur offers for sale a delectable tray of watermelon. Many developing countries like Bangladesh are improving the diets of their people through agricultural diversification.

IFDC Annual Report—1988

Contents

Page

List of Acronyms 2
Fertilizer Terms and Other Abbreviations 3
Managing Director's Letter 4
Global Fertilizer Situation--1988 6
New Impetus for Fertilizer Sector Development in Africa 9
West Africa Programs 10
Introduction 10
Economics Research and Fertilizer Development Program 11
Human and Agromineral Resource Development 13
Agronomic Research 16
East and Southeast Africa Fertilizer Research Program 22
Technical Assistance in Africa 24
Growth Maintained in Asian Fertilizer Sector 29
Introduction 30
Research Activities 30
Nitrogen Research 30
Phosphorus Research 34
Sulfur Research 35
Technical Assistance 37
National Programs 38
Latin America Presents Different Fertilizer Picture 41
Introduction 42
Research Activities 42
Technical Assistance 46
Human Development Component Gains Momentum 48
Partners in Developing Human Resources 49
1988 Training Activities 49
General Training Programs 50
Specialized Training Programs 51
Workshops 52
Participants' Evaluation 53
Extending Impact Through Special Global Projects 54
Agrominerals Data Bases 54
Fertilizer Use Efficiency Data Base Management 54
Crop Growth Simulation Modelling 55
New Test for Phosphorus Fertility Evaluation 57
Financial Report 59
1988 IFDC Publications 66
IFDC Board of Directors 69
Staff 70
IFDC Addresses 71

Note: If desired, the 8-page profile of IFDC can be removed from the Annual Report and kept as a separate document.

List of Acronyms

AARD—Agency for Agricultural Research and Development
ABOCOL—Abonos Colombianos, S.A.
ACL—Agri-Chemicals Limited
AFTMIN—African Fertilizer Trade and Marketing Information Network
APPI—Assosiasi Produsen Pupuk Indonesia
BADC—Bangladesh Agricultural Development Corporation
BARC—Bangladesh Agricultural Research Council
BGR—Bundesanstalt für Geowissenschaften und Rohstoffe
BRGM—French Bureau for Geological and Mining Research
CEFER—Centro de Estudos de Fertilizantes
CERES—Crop Evaluation Through Resource and Environment Synthesis
CIAT—Centro Internacional de Agricultura Tropical
CIMMYT—International Maize and Wheat Improvement Center
ESCAP—Economic and Social Commission for Asia and the Pacific
FADINAP—Fertilizer Advisory Development and Information Network for Asia and the Pacific
FAI—Fertiliser Association of India
FERTICA—Fertilizantes de Centro America
FINNIDA—Finnish Department for International Cooperation
FINTRA—Fiduciaria de Inversiones Transitorias, S.A.
FPA—Fertilizer and Pesticide Authority
FPM—FPM Sendirian Berhad
FPRP—Fertilizer Policy Research Project
GEOREF—Geological Reference File
GSFC—Gujarat State Fertilizer Company Ltd.
GTZ—Deutsche Gesellschaft für Technische Zusammenarbeit
IBSNAT—International Benchmark Sites Network for Agrotechnology Transfer
ICA—Instituto Colombiano Agropecuario
ICARDA—International Center for Agricultural Research in the Dry Areas
ICRISAT—International Crops Research Institute for the Semi-Arid Tropics
IFDC—International Fertilizer Development Center
IFFCO—Indian Farmers' Fertiliser Cooperative, Ltd.
IFPRI—International Food Policy Research Institute
IGADD—Intergovernmental Authority on Drought and Development
IITA—International Institute of Tropical Agriculture
IRRI—International Rice Research Institute
KKV—Konkan Krishi Vidyapeeth
LEI—Agricultural Economics Research Institute of the Netherlands
MIPCO—Minjingu Phosphate Company
NAFCON—National Fertilizer Company of Nigeria Limited
NFDC—National Fertilizer Development Center
NORAD—Norwegian Agency for Development
ORSTOM—Office de la Recherche Scientifique et Technique de Outre-Mer
OTP—Office Togolais des Phosphates
RNTV—Radio Netherlands Television
SFRP—Soil Fertility Restoration Project
SOQUIMICH—Sociedad Quimica y Minera de Chile
TFC—Tanzania Fertilizer Company
TVA—Tennessee Valley Authority
UNDP—United Nations Development Programme
UNIDO—United Nations Industrial Development Organization
USAID—U.S. Agency for International Development
USGS—United States Geological Survey
WAFMEN—West African Fertilizer Management and Evaluation Network

Fertilizer Terms and Other Abbreviations

CHPT—cyclohexyl phosphoric triamide
CHTPT—cyclohexyl thiophosphoric triamide
DAP—diammonium phosphate
DCD—dicyandiamide
nBPT—n-butyl phosphoric triamide
nBTPT—n-butyl thiophosphoric triamide
PAPR—partially acidulated phosphate rock
PPDA—phenyl phosphorodiamidate
REI—residual effectiveness index
RLCU—reactive-layer coated urea
SAT—semiarid tropics
SCU—sulfur-coated urea
SSP—single superphosphate
TDP—transportation discount point
TSP—triple superphosphate
USG—urea supergranules

Managing Director's Letter

Because this is my last opportunity as IFDC's Managing Director to prepare a message for the Annual Report, quite naturally I pause to ponder the events of the past 14 years. During the past decade and a half, I have seen this institution emerge from the concept stage to a center that is impacting the agricultural sectors of the developing world through its programs in fertilizer research, training, and technical assistance.

In the beginning stages—1974/75—only a handful of staff members were on board. Today's staff, recruited from more than 20 countries, numbers 148—28 of which are outposted to developing countries around the globe.

As for our funding base, I have witnessed its growth from only two donors, with a budget of approximately US $3.5 million in 1975, to more than nine major donors and several other funding sources for a total budget of US $11.2 million in 1988.

Looking back over IFDC's accomplishments in research during the past 14 years, we can take pride in knowing that the Center has gained recognition as a basic source of information on the phosphate deposits of the world. Phosphate research and development by IFDC has enhanced the understanding of conditions under which indigenous deposits of phosphate rock may be used for direct application or when partially acidulated phosphate may be an appropriate alternative in developing-country agriculture. IFDC has also established itself internationally as a leader in the technology of identifying nitrogen losses and means to curb these losses. The magnitude and causes of nitrogen losses in flooded and rainfed systems, particularly ammonia volatilization, have been quantified and put into perspective. The deep placement of urea, use of inhibitors, and/or coating of urea to curb these losses have been studied to determine under which conditions these modifications can effectively improve efficiency. The results on controlling urea dissolution, decreasing nitrogen losses, and increasing nitrogen uptake by plants are encouraging. However, environmental concerns rather than economics or improved agronomic efficiencies may be the driving force for the development of these products for general agricultural use. In the years to come, the theme of this year's Annual Report—sustainable agriculture—will assume even greater importance in IFDC's efforts to increase food production through the development of more efficient and effective fertilizers.

Bangladesh continues to diversify its agriculture by introducing more fruits and vegetables into its crop production plans. IFDC has played a role in this effort through interaction with BADC and other key institutions—a continuing collaborative effort toward developing greater effectiveness of that country's fertilizer sector.

As I reminisce about the past years, I am struck by the phenomenal growth of our training program component. I have observed the growth of IFDC's training offerings from 2 or 3 with 20 participants in 1976 to 25 group and individual programs with 299 participants in 1988. As of December 31, 1988, we have trained 3,488 people from more than 100 countries.

In the technical assistance area, IFDC's multidisciplinary, multilingual staff members have provided unbiased opinions regarding most facets of fertilizer sector development including fertilizer policy aspects in more than 80 countries around the world.

In summary, IFDC has made significant progress in helping to develop efficient fertilizer sectors in developing countries through research, training, technical assistance, and country-specific studies. In carrying out its mission of developing improved fertilizers and fertilizer practices for countries of the tropics and subtropics, IFDC has developed important linkages and collaborative programs with national and international institutions. I am most proud of the fact that in the developing countries IFDC is viewed as an unbiased source of information and advice and that our services are often used in this way.

Donald L. McCune
Managing Director

Global Fertilizer Situation—1988

Consumption

During 1988 total world consumption of fertilizer nutrients amounted to 140.52 million tons; of that amount the developing countries accounted for 56.76 million tons, or 40% of the total.

Global nitrogen consumption during 1988 amounted to 76.0 million tons, up from 71.7 million tons for the previous year or an increase of 6%. More than 80% of the increase in global nitrogen use was contributed by an increase in apparent nitrogen consumption in East Asia, primarily in China. North America, the U.S.S.R., and Latin America experienced about 2%-3% increase in nitrogen use; whereas, Western Europe, Eastern Europe, and Africa experienced a 1%-3% decline. In Africa nitrogen use decreased in both South Africa and sub-Saharan Africa.

Like global nitrogen use, global phosphate use also increased by 6%—from 34.7 million tons in 1987 to 36.9 million tons in 1988. Again, most of this increase in global phosphate use was contributed by an increase in apparent consumption in East Asia, mainly in China. All regions and subregions, except Eastern Europe and Africa, experienced increases in phosphate use. The percentage increases ranged between 1.5% in South America and 9.0% in North Africa with the exception of East Asia, which experienced a 32.8% increase.

Global potash consumption amounted to 27.5 million tons in 1988, up from 26.2 million tons for the previous year or a 5% increase. An increase in apparent potash use in East Asia is responsible for most of this increase in global potash use. Eastern and Western Europe, South and sub-Saharan Africa, and West Asia experienced significant declines in their potash use; whereas, North America, the U.S.S.R., Latin America, and South Asia experienced significant increases in potash use.

Production

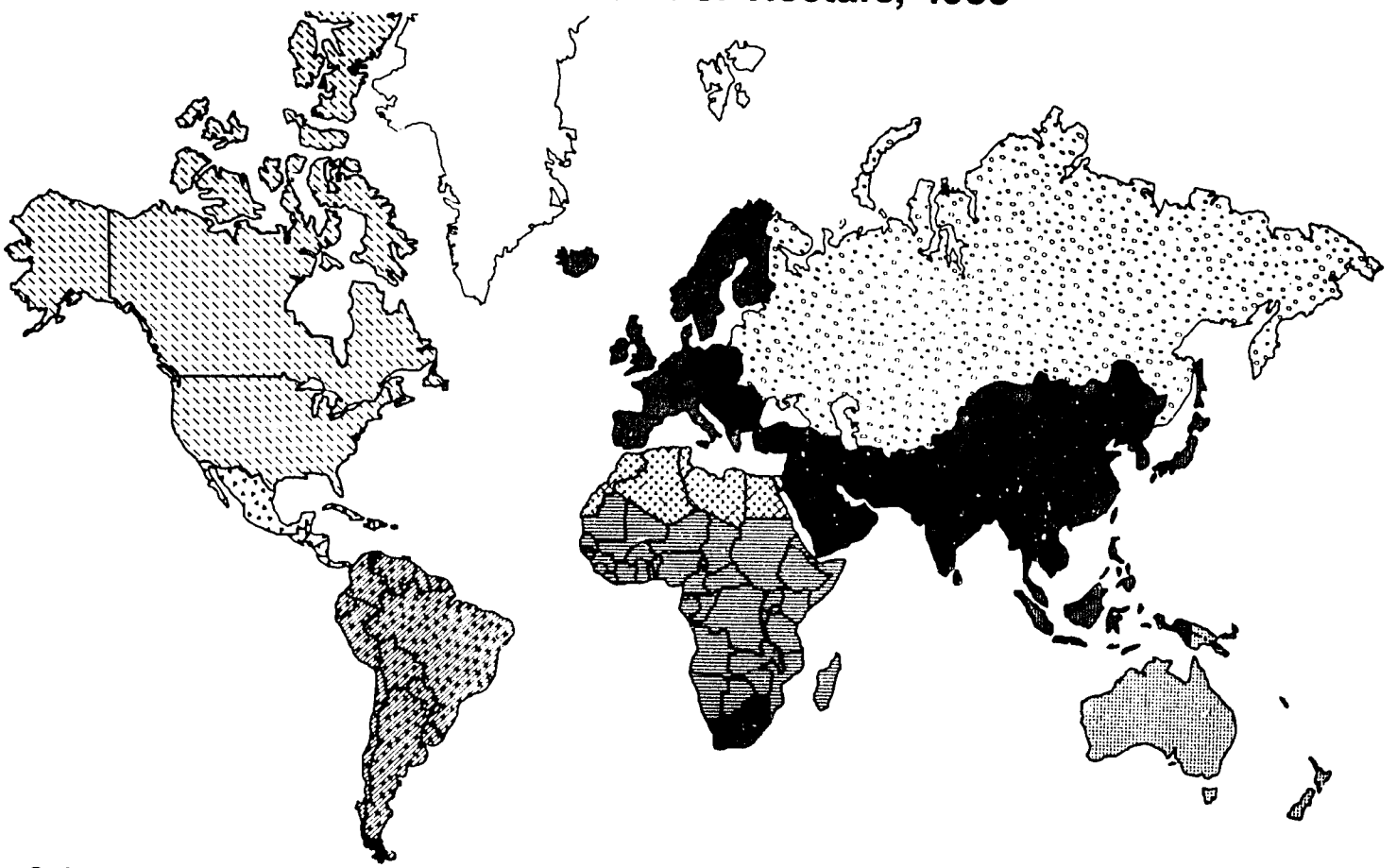
Global nitrogen production during 1988 was 82.2 million tons, up from 77.4 million tons for the previous year or a 6% increase. A little more than one-half of the increase in global nitrogen production was contributed by an increase in production in Asia, and about 20% by an increase in production in North America. Asia's nitrogen production increased by about 10%, and both East and West Asia experienced more than 10% increases in their nitrogen production. Africa and Oceania also experienced more than 10% increases in their nitrogen production. Although sub-Saharan Africa's nitrogen production increased by 76%, it was from a low base of 108,000 tons. The new ammonia-urea plant in Nigeria contributed most of this increase in production in sub-Saharan Africa. North America and Latin America experienced 6%-7% increases in nitrogen production.

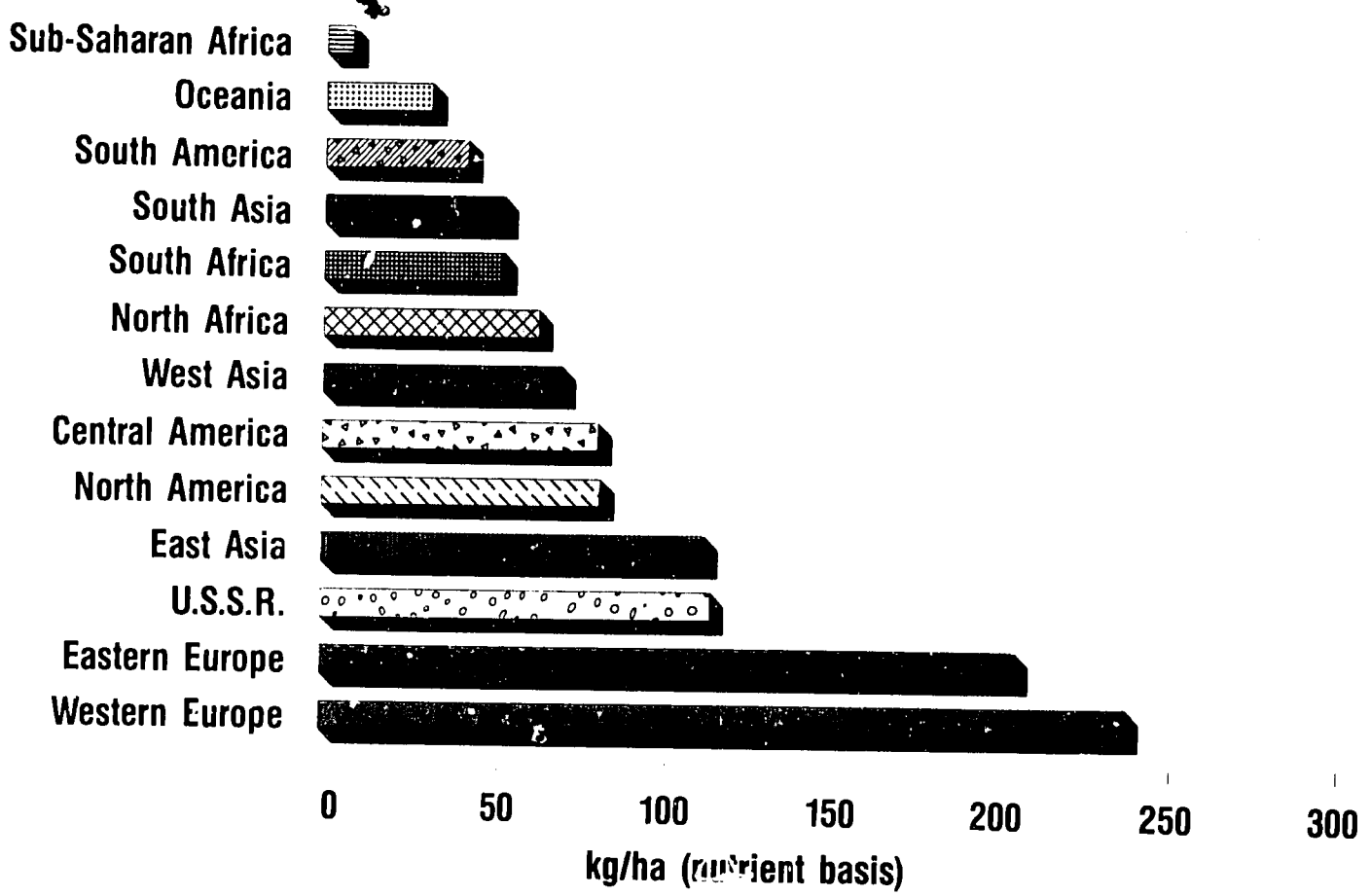
Like global nitrogen production, phosphate production also increased by 6%—from 37.3 million tons in 1987 to 39.6 million tons in 1988. Although Asia contributed the most to this increase in global phosphate production, North America and North Africa also contributed significantly. New phosphate plants in Central America added 60% to its phosphate production. Unlike Central America, South America's phosphate production decreased. Eastern Europe, sub-Saharan Africa, and South Africa also experienced declines in their phosphate production.

Global potash production increased by 6%—from 28.8 million tons to 30.5 million tons. Most of this increase in global potash production came from increases in potash production in North America, Western Europe, and the U.S.S.R. All three regions experienced 6%-7% increases in potash production. Although East Asia and South America experienced high percentage increases, these were on a very small base.

Excerpted from *Global Fertilizer Perspective, 1960-95: The Dynamics of Growth and Structural Change*, by Balu L. Bumb, IFDC, 1989.

Fertilizer Use Per Hectare, 1988





Africa Fertilizer Situation

Consumption

Although Africa consists of more than 45 countries and accounts for about 12% of the world population, it accounted for less than 3% of total world fertilizer consumption in 1988. Two-thirds of this consumption was concentrated in five countries in North Africa and the Republic of South Africa. Thus, sub-Saharan Africa, with about 40 countries and 9% of the world population, accounted for only one-third of total fertilizer consumption in Africa, and less than 1% of the global fertilizer consumption in 1988.

In absolute terms, Africa's total fertilizer consumption increased from 0.53 million tons in 1960 to 2.8 million tons in 1980 and 3.5 million tons in 1988. Nitrogen use increased from 0.2 million tons in 1960 to 1.5 million tons in 1980 and 1.9 million tons in 1988. Likewise, phosphate and potash use increased from 0.23 million and 0.08 million tons in 1960 to 1.14 and 0.44 million tons in 1988, respectively.

Africa experienced a slowdown in its fertilizer use during the 1980s. Compared with 9.4%/year growth in the 1960s and 6.2%/year growth in the 1970s, total fertilizer use increased only at about 2.8%/year during the 1980-85 period. Most of this slowdown was caused by significant declines (3.8%/year) in total fertilizer use in South Africa. Also, foreign exchange shortages and unfavorable weather conditions in many sub-Saharan African countries contributed to this slowdown.

Production

Africa accounts for a rather small proportion of total world fertilizer production. In 1988 with 3.7 million tons of total production, Africa accounted for less than 3% of total world production.

Total fertilizer production increased from 0.3 million tons in 1960 to 1.9 million tons in 1980 and 3.7 million tons in 1988. Nitrogen production increased from 0.1 million tons in 1960 to 0.8 million tons in 1980 and 1.8 million tons in 1988, while phosphate production increased from 0.2 million tons in 1960 to 1.1 and 1.9 million tons in 1980 and 1988, respectively. Africa does not produce potash, although between 1970 and 1978, a potash mine in the Congo produced some potash, but due to flooding it was closed in 1978.

Not only does Africa contribute very little to world fertilizer production but also most of its production is concentrated in North Africa. In 1988 North Africa accounted for 74% of total African fertilizer production. Another 18% of production came from South Africa and 8% from sub-Saharan Africa.

Excerpted from *Global Fertilizer Perspective, 1960-95: The Dynamics of Growth and Structural Change*, by Balu L. Bumb, IFDC, 1989.

West Africa Programs

Introduction

The establishment of IFDC-Africa in Togo during 1987 reflected the concern and commitment of IFDC and its donors to ensure that the constraints to increased fertilizer use in sub-Saharan Africa were accurately identified and initiatives taken to overcome them. While the need for increased fertilizer use is widely accepted, the task of developing the fertilizer sector to play a dynamic role in food crop production is generally acknowledged to be formidable.

The extent and complexity of the constraints to fertilizer sector development pose a major challenge for the national institutions in the region and international development agencies. The provision of increased quantities of fertilizer for African farmers through cost-effective production and delivery systems is difficult because it involves tackling some of the fundamental problems that are at the heart of economic development in the region. Institutional debilitation, poor infrastructural development, and excessive state control and involvement in the provision of goods and services, all contribute to the inefficient supply and generally high prices of fertilizers in the region. In the absence of effective initiatives or interventions, it is clear that there will be no substantial progress to increase fertilizer use for food production in the region. IFDC recognizes that progress will only be possible if a comprehensive and integrated package of initiatives is implemented in the areas that critically affect the availability and cost of fertilizers in the region.

Fertilizer plays a very important role in national agricultural policies that aim to achieve self-sufficiency in food production. If increased fertilizer use is not a central part of national strategies to increase food production, then it is unlikely that supplying fertilizers cost effectively to farmers will receive high priority. While there is general acquaintance with the nature of the policy constraints at national levels, there is a lack of detailed data and the related analysis that is essential for medium- and long-term decision making at national and regional levels. IFDC, in cooperation with IFPRI, has initiated a Fertilizer Policy Research Project to assess the problems in tropical African countries and obtain the benchmark data that can guide and support fertilizer policy development.

While the small size of the African market is a contributing factor to the relatively high farm-gate prices of fertilizers in the region, it is widely accepted that inefficiencies in procurement, port handling, storage, transportation, and distribution at national levels are all major factors affecting the high cost of this input to farmers. As is the case with fertilizer policy, there is limited information on fertilizer supply in the region. Through the African Fertilizer Trade and Marketing Information Network (AFTMIN), which was established in 1987, IFDC is fostering regional collaboration to strengthen information collection and exchange in relation to fertilizer marketing and supply in the region. Through greater communication and interaction among fertilizer marketing personnel, AFTMIN promotes the collection and analysis of data at country and regional levels, covering such areas as systems of procurement and distribution and the costs and margins in fertilizer trade in the region.

While the above initiatives are helping to address the problems in relation to fertilizer policy and supply, it is also important to examine and address the constraints to fertilizer adoption at the farm level. For the success of initiatives in marketing and supply, it is essential that the demand for fertilizer is assessed and forecasted accurately. The actual levels of demand are determined by a multiplicity of factors, some of which can be

Mr. G. Akakpo Foly (second from left), Director of Technical Cooperation, Ministry of Foreign Affairs, Togo, is briefed by Dr. Uzo Mokwunye (left), Coordinator of Agronomic Research, IFDC-Africa, on IFDC fertilizer trials at Davié, Togo. IFDC works closely with national programs in Togo and strengthened its research programs in all agroecologies during the year.

examined and quantified through agricultural research that focuses primarily on the constraints to fertilizer use at the farm level. Having obtained considerable data on response levels to various chemical fertilizers in the region, IFDC research focuses increasingly on the development of national capabilities to undertake fertilizer research and the accurate identification of problems and barriers to increased adoption and use of fertilizer in specific agroecologies and farming systems in the region.

Ultimately, policies that provide fertilizers in efficient and cost-effective ways to farmers will have little impact unless fertilizer-based food production technologies are transferred effectively to farmers. The widespread provision of information on new crop production technologies in ways that are meaningful for extension personnel and farmers is a prerequisite for effective adoption by farmers. To strengthen the efforts and impact of field personnel in getting the fertilizer message across to farmers, the Communications, Documentation, and Training Program provides special fertilizer information services for national personnel and training in fertilizer extension communications.

Finally, an integrated approach to fertilizer sector development of this region should also focus on the potential of indigenous agromineral resources to meet the fertilizer needs of the region. IFDC took the initiative during the year to establish the West African Agromineral Research and Development Program, which will concentrate on collaborative efforts to identify, assess, and eventually devise development plans for the exploration and development of agromineral resources in the region.

The development of strong links with national programs is central to progress in the region. IFDC has worked closely with 20 countries in sub-Saharan Africa during the year. Ambassadors from the United States of America, the Union of Soviet Socialist Republics, and France visited IFDC's office in Togo during the year for information and briefing on program activities. IFDC's approach to regional collaboration for fertilizer sector development in sub-Saharan Africa has centered on the network concept to facilitate information dissemination and exchange, foster cooperation between countries, and gain commitment from within the region for initiatives and projects in fertilizer research, training, and technology transfer.

Economics Research and Fertilizer Development Program

Fertilizer Policy Research Project

The Fertilizer Policy Research Project (FPRP) is jointly executed by IFDC and IFPRI. The purpose of the project is to assist countries in sub-Saharan Africa to identify key variables affecting the supply and demand of fertilizer and to design and evaluate various fertilizer policies that may stimulate the development of the fertilizer sector.

Progress for the initial working year of 1988 included: (1) the establishment of the policy team, (2) an introductory workshop with national participants to set the FPRP research agenda, and (3) an in-depth review of fertilizer policy literature. Senior staff for the Togo-based FPRP team were identified and recruited during 1988 and assumed their duties in late 1988. The FPRP team includes an IFPRI economist, who is the team leader, an IFDC associate economist, and two local research assistants. This team coordinates fertilizer policy research in sub-Saharan Africa with IFDC and IFPRI personnel.

The first FPRP workshop was held from April 5-7, 1988, in Lomé, Togo. Policymakers and policy analysts from Ministries of Planning and Agriculture from 10 invited countries participated in the workshop. In addition to country papers presented on fertilizer use constraints, papers were also presented by six senior IFDC and IFPRI staff members. Representatives from USAID, International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and International Maize and Wheat Improvement Center (CIMMYT) also attended. The economic potential for fertilizer use, the lack of proper statistics and information for policy decisionmaking and design, and institutional reform pertaining to privatization and fertilizer price subsidies were highlighted and discussed.

An in-depth review of fertilizer policy literature was prepared by IFDC staff. The paper, "Fertilizer Policy for Sub-Saharan Africa: A Review of the Literature," covers a large volume of the literature relevant to enhancing the role of fertilizer-related policies and programs for increased food and agricultural production in the countries of sub-Saharan Africa. The paper includes annotated summaries of literature and suggestions for fertilizer policy research.

The April workshop and the in-depth fertilizer policy literature review provided the

background information and a synthesis of initial research priorities from which the FPRP research program was developed. The research agenda for 1989 includes: (1) the grouping of sub-Saharan African countries by agricultural and fertilizer resource endowments, constraints, and sector development for policy analysis purposes; (2) initiating an analysis of the economic potential for fertilizer use in sub-Saharan Africa which includes (a) the mapping of physical fertilizer-crop responses across agroecological zones and (b) the associated economic analysis of the physical fertilizer-crop responses; (3) research on privatization and fertilizer price subsidy issues; (4) the initiation of a policy analysis network with national fertilizer policy programs, including an annual workshop; and (5) establishment of a fertilizer policy data management system.

Fertilizer policy research for the coming year includes the investigation of macroeconomic policy changes on fertilizer supply in Senegal, the comparison of the returns from fertilizer investment to other household investment alternatives in Senegal and Burkina Faso, the study of fertilizer purchase behavior and credit use in Zambia, and the effect of structural adjustment programs on fertilizer use in Gambia.

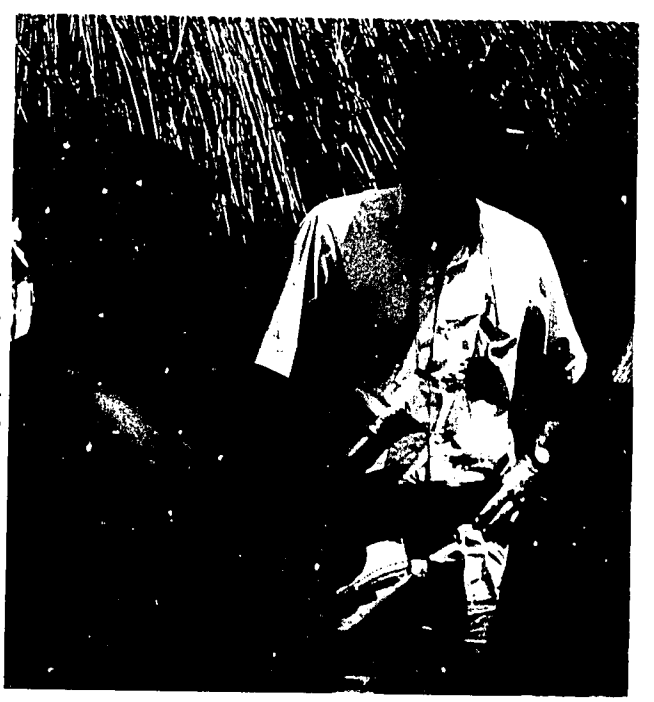
Monitoring, Collection, and Dissemination of Fertilizer Market Information

Following the inception of AFTMIN in 1987, the marketing staff initiated a number of projects to strengthen fertilizer information exchange and channels of communication in the region. Apart from the informal channels of communication, two special initiatives were taken during the year to organize and target fertilizer trade information more effectively. A fertilizer trade information telex service was initiated on a pilot basis for 3 months and following a survey of recipients, a decision was taken to continue providing the service to 20 countries in sub-Saharan Africa.

A monthly fertilizer market intelligence bulletin—*African Fertilizer Market*—was also published from July 1988 to provide background information on fertilizer trade and marketing for 40 countries in sub-Saharan Africa and periodic updates and reviews of developments in the fertilizer sectors of individual countries. Both the telex service and *African Fertilizer Market* are provided in English and French.

The marketing staff members respond to *ad-hoc* requests from AFTMIN correspondents and international organizations for fertilizer trade information pertinent to the region. AFTMIN held its first annual meeting in November 1988. Seventeen participants from 12 countries and five observers attended the meeting with an agenda that examined areas such as privatization, costs of importing fertilizers, freight and marketing costs, and fertilizer supply in the region. Currently, 12 countries are involved: Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Lesotho, Madagascar, Niger, Nigeria, Rwanda, and Togo. The major aim of AFTMIN is to overcome the lack of knowledge and current information, which is often cited as a major reason for inefficiency in procurement, production, marketing, distribution, and use of fertilizer in the region.

The marketing staff members have also researched and presented two background papers for AFTMIN members on Fertilizer Marketing Costs and Margins in sub-Saharan Africa and the Supply of Fertilizer in sub-Saharan Africa. AFTMIN activities also include detailed studies of the fertilizer sectors within individual countries. The desk and field research for the first study in the Republic of Benin was completed during the year. The Agricultural Economics Research Institute of the Netherlands (LEI) is cooperating in conducting these studies, and a steering committee has been established to guide and review the overall study process during the coming years.



Rein Coster, IFDC-Africa's Market Analyst, interviews the village Chief of Ndali in Northern Benin as part of research for the IFDC study of the fertilizer sector in the Republic of Benin. The study is the first in a series of country studies in West Africa, and fieldwork was completed for it in 1988.

The IFDC Project team for marketing includes a market analyst and a research assistant. With the development and improvement of services for the region, it is envisioned that additional personnel will be recruited to fill positions in data base management and marketing. The development of a fertilizer data base for sub-Saharan Africa will be a priority during the coming year, and the regional survey on marketing costs and margins will be conducted annually. With AFTMIN now formally established, IFDC can move to collect, streamline, and target the dissemination of fertilizer information through a strong network of regional collaborators.

Human and Agromineral Resource Development

Fertilizer Information Dissemination and Technology Transfer

Fertilizer Library and Information Services

The provision of the most up-to-date information on fertilizer use and technology transfer in the region was one of the major activities during 1988. During the year, library and information services were further developed.

In 1988 the development and provision of library services to meet the specific needs of the region received major emphasis. A further 600 acquisitions including textbooks, conference proceedings, reports, journals, and periodicals were procured; this brought the total acquisitions at the end of 1988 to 1,200, including 170 periodicals and journals. Most of the new acquisitions relate directly to food crop technology development and transfer in the region; all major reports on fertilizer developments in the region are now available for national personnel, students, and visitors. In terms of fertilizer information for food crop technology in the region, the library staff members have taken measures toward developing a resource of state-of-the-art knowledge and information.

The computerization of the data base is also desirable to provide an improved variety and range of fertilizer information services for national personnel. The ultimate aim is to provide literature search facilities and to store and retrieve information efficiently using available software and technology for library services. Work has started on the complete computerization of the data base.

To serve francophone as well as anglophone African countries, IFDC obtains acquisitions in French and English and a special French-English thesaurus will be prepared to ensure that all users can obtain complete knowledge on the range of acquisitions—whether in English or French. The library services are helping to overcome the lack of a central, comprehensive source of fertilizer information in the region; the service has been promoted among national program personnel.

After consultations and discussions with national program personnel involved in fertilizer technology transfer in West Africa, a workshop on Fertilizer Technology Transfer was conducted in September 1988 in Lomé, Togo. A total of 21 participants from seven West African countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Niger, and Nigeria) attended, and 14 speakers contributed to the workshop.

Dr. T. Arokoyo, Senior Extension Specialist, Agricultural Extension and Research Liaison Services (AERLS), Ahmadu Bello University, Zaria, Nigeria, addresses participants at the IFDC Workshop on Fertilizer Technology Transfer, held in Lomé, in September. The Workshop was part of IFDC's consultation with senior extension personnel in West Africa prior to the organization of in-country training programs for field personnel in fertilizer extension communications.

The major goal was to obtain the most up-to-date briefing and analysis on developments in fertilizer technology transfer in the region and to involve senior personnel at national levels in the identification of training needs and in the preparation of training programs for in-country implementation in cooperation with IFDC.

The major output of the workshop came from three working groups that identified the training needs of national field personnel involved in fertilizer technology transfer with specific emphasis on extension communication. The critical and widespread need for extension support materials was highlighted and probed. Specific suggestions were made for followup

in-country training programs; the first training program is planned for implementation in early 1989 for field extension officers from two regions of Ghana.

Publications and Training Support Materials

Preliminary planning work has been completed for the first two issues of *Africa Fertilizer Review*—a new biannual magazine-style publication that will be published, beginning in 1989. The magazine will provide a biannual update and review of international and national activities in fertilizer research, development, and technology transfer. The magazine will provide coverage and review of developments in fertilizer research, policy, agronomy, trade, marketing, technology, transfer, and training.

Africa Fertilizer Review will provide new opportunities for greater exchange of fertilizer information between international and national personnel involved in fertilizer development activities in the region. Specifically, it will allow those involved with tropical soils, agronomy, and cropping systems generally to publish the findings of their research and development activities. African research scientists and commercial and extension personnel will be encouraged to contribute news articles and short scientific papers for publication. The magazine will be edited and produced by IFDC with primary emphasis on serving the needs of national partners and collaborative projects in sub-Saharan Africa.

The design and production of fertilizer extension guides to be used by national extension personnel were initiated.

Pilot Projects With Modern Communications Technologies

While the major activities during the first 2 years of the project have concentrated on the improvement of fertilizer information services and the development and implementation of new approaches to training in fertilizer technology transfer. The potential of new communications technologies such as video for improved communication of the soil fertility and fertilizer message in the region was explored. In Togo, IFDC has cooperated closely with the Togolese Television Service to provide input and footage for an episode of *Carnet Rural*, a series that focuses on rural development in Togo. The rationale for and the scope of the IFDC activities in agronomic research and training are covered in the program and some of the footage will be used for future IFDC video projects.

There is also increasing interest in the agricultural and environmental problems of West Africa by the producers of European and American television programs. Radio Netherland's Television (RNTV) has taken an active interest in coverage of environmental and agricultural aspects of rural development in West Africa. Preliminary discussions with RNTV focused on the possibility of a series of productions covering agricultural production and sustainability issues and the development of indigenous resources.

West African Agromineral Research and Development Program

It is widely known that significant deposits of phosphates and other agrominerals exist in many parts of West Africa. These resources, however, have not been developed or exploited to supply inputs for agricultural production in the region at a time of high population growth rates and declining per capita food production in the region.

There are various reasons why most of these deposits have not been exploited. Potential areas of development are landlocked or in remote locations, and there are limited financial resources and infrastructure. With the exception of deposits in Senegal and Togo, which are already exploited for export, most of the deposits are still at the geological survey stage. Only phosphate materials from Burkina Faso, Mali, and Niger have been tested for direct application or for application after simple processing. The geological data necessary for economic evaluation of the resources for fertilizer are not yet available. In relation to the reactivity or agricultural potential of deposits, research data are few and scattered. Thus, a systematic research program is needed to provide information on the potential of these deposits for fertilizer use in the region.

During 1988 the West African Research Program on Agrominerals was initiated in collaboration with the Government of the Federal Republic of Germany. This program aims to evaluate some of the many phosphate and other agromineral deposits that have not yet been studied in the West African region. This process involves the exchange of scientific information at a regional level by scientists working on these deposits. The network will help scientists identify problems related to the identification and exploration of agrominerals and start a systematic process that will assess the potential of these deposits for fertilizer use in support of regional food crop production.

The research program has two central aims: (1) to understand

aspects and characteristics of regional geology, which explain distribution of phosphates and other agromineral deposits and (2) to obtain political, technological, and economic data that will lead to the identification of pilot projects with maximum potential for success.

Regional Workshop

A workshop on West African Agrominerals was organized by IFDC in 1988 in Lomé, Togo, to initiate regional cooperation for the research program. The workshop was funded by the Government of West Germany and hosted by the Government of Togo. Sixteen delegates from nine countries attended the workshop. Three observers from the West German Government, one from Office de la Recherche Scientifique et Technique de Outre-Mer (ORSTOM)-Togo, and five IFDC staff attended the meeting.

The objective of the workshop was to establish a regional network for geological scientists, organizations, and institutions operating in West Africa. This network aims to provide training facilities for personnel involved in the geological exploration of agrominerals, undertake research to identify and eliminate constraints to fertilizer use, foster regional cooperation for development of agromineral resources, and determine potential pilot projects and programs.

The main topics covered during the workshop included IFDC's experience in the use of indigenous phosphate for fertilizer production in tropical Africa; an overview of nonmetallic minerals in West Africa; and an overview of phosphate deposits, their development to date in West Africa, and activities in fertilizer mineral development in the region.

In addition, country reports were presented on the state-of-the-art of ongoing geological work in the nine countries including descriptions of the location and occurrence of deposits, mineralogy, and geochemistry, mining potential, exploitation methods and processing, and chemical treatment aspects. One of the main aspects of the program is the establishment of a data base on agrominerals. It will collect and retain pertinent information on agrominerals available in West Africa. In order to overcome problems related to the reliability of data, the program has started to compile a complete bibliography on agrominerals for each of the nine participating countries and undertake a systematic review of Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the French Bureau for Geological and Mining Research (BRGM) computerized literature, including the Geological Reference File (GEOREF) and IFDC raw materials data bases.

IFDC started study tours of selected participating countries in order to (1) identify, establish, or reinforce existing contacts with appropriate geological organizations and ministries, (2) collect publications or listings of existing reports or publications, (3) obtain representative agromineral samples for analysis, (4) assess the interest of governments in agromineral research, and (5) identify potential projects.

Specific objectives of the network include:

1. Identification and documentation of agromineral raw materials,
2. Development of the geological skills required to locate and evaluate these resources,
3. Dissemination and exchange of information between regional scientists and the promotion of cooperation between organizations involved in the development of agromineral resources in the region, and
4. Assessment and evaluation of the potential of local agromineral raw material to increase food production in the region.

The agromineral network will also develop a data base on raw materials and deposits that have potential for fertilizer development and use. This data base will collect all existing information from studies undertaken in the region and in relation to technical areas such as mineralogical characterization and processing of ores into fertilizer products. The data base will be an important part of IFDC's regional information service for agromineral development. Agromineral program activities to initiate and develop contacts and cooperation in the region are already underway in Benin, Burkina Faso, Ghana, Mali, Mauritania, Niger, and Togo.

Regional Collaboration and Training

Because of the scale and complexity of the agricultural development needs in the region and the relatively limited resources and funding available, IFDC's office in Togo has implemented a program of collaboration with governments and national institutions involved in agricultural research and technology transfer. Central to the IFDC approach has been the formation of regional networks (described elsewhere in this report) in key areas for fertilizer sector development such as fertilizer marketing and agromineral development.

The networks allow the organized and systematic exchange of information between countries with common

problems and interests in the region. Annual meetings, workshops, and seminars enable national personnel to update their knowledge, share experiences, and discuss ways to overcome problems with counterparts from national and international organizations.

During the year IFDC's staff stationed in Togo organized the following five programs—four of which brought national specialists together for the first time to discuss problems and propose new initiatives at the regional level. The following programs were organized during the year:

1. West African Fertilizer Management and Evaluation Network (WAFMEN).
2. Workshop on Fertilizer Policy in Tropical Africa.
3. Workshop on West African Agrominerals.
4. Workshop on the Transfer of Fertilizer Technology.
5. First Annual Meeting of AFTMIN.

With the exception of the existing WAFMEN network, the other four programs involved the first formal meetings of national counterparts in relation to specific aspects of fertilizer development in the region. The average attendance during the programs was 20 persons representing 8-16 countries. More than 80 new contacts with national collaborators were established during the year.

Training priorities for 1989 were also identified during the year. The emphasis will be on three areas—support for agronomic research, fertilizer marketing, and technology transfer at in-country levels.

Programs are scheduled for implementation in the following areas:

1. Statistical and Economic Analysis of Fertilizer Research Data, Lomé.
2. Development of Fertilizer Extension Support Materials. In-country program, Ghana.
3. Relevant Fertilizer Supply Strategies, Lomé.

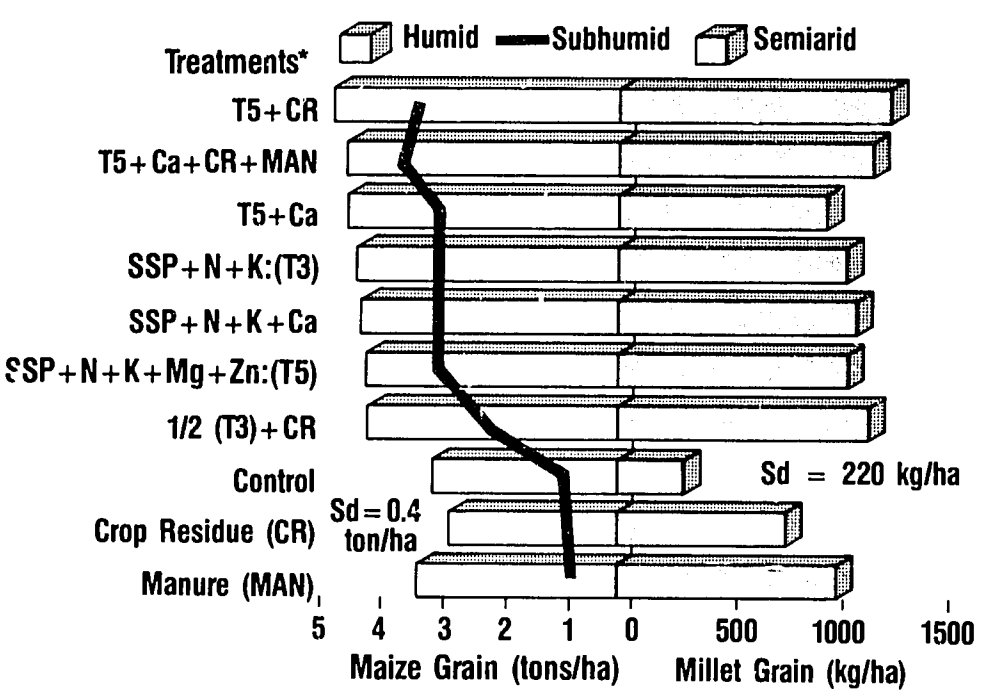
Agronomic Research

Agronomic Research Program

In most of West Africa, the risk associated with costly inputs such as fertilizer in the event of crop failure is a major constraint to increased fertilizer use. To reduce the risk factor and promote fertilizer use, agronomic studies geared toward more efficient use of fertilizers are necessary. Such studies should define the types and quantities of fertilizers to use for each crop and cropping system and also define the management practices to be adopted to improve fertilizer use efficiency. Finally, these studies should evaluate the long-term effects of fertilizers on the environment.

These tenets have provided important guidelines for IFDC's *Fertilizers and Sustainable Agriculture* research program for West Africa. At the benchmark sites in Togo and Niger (covering the primary agroecological zones of West Africa), a number of trials have been set up to determine the long-term soil fertility needs of the soils and crops, the interactions between the various nutrients, and the residual effectiveness of phosphate fertilizers.

In order to assess the sustainability of extensive agriculture based on the use of inputs, IFDC's scientists established a series of long-term experiments in the different ecological zones of Togo and Niger: Amoutchou (1987) and Davié (1988) in the humid region, Tchitchao (1987) in the subhumid region, and Sadore (1987) in the semiarid Sahel. The effects of various nutrient combinations and fertilizer sources, including organic sources, on plant growth are evaluated in these trials.



* See Table 1 for list of treatments.

Figure 1. Long-Term Soil-Fertility Evaluation.

Dr. Uzo Mokwunye, Coordinator of Agronomic Research, stationed in Togo, discusses field trials at Davié, Togo, with Dr. A. K. Johnson, Associate Scientist, West Africa Agromineral Program. IFDC is continuously evaluating the benefits and potential of materials derived from regional phosphate rock as fertilizers for food crop production.

A summary of the salient treatments in these experiments is provided in Figure 1. It is clear that the response to fertilizer is more dramatic as one moves from the humid to the semiarid zone. The response to phosphorus (as single superphosphate [SSP]) in the semiarid tropics (SAT) confirms its importance in this environment. The optimum NPK treatment—T_3 (see Table 1)—as determined in previous years seems to be a complete fertilizer as additions of lime or magnesium and zinc did little to increase yield any further. Addition of crop residue as a complement to NPK shows a small yield advantage. However, through the use of crop residue it is possible to reduce the NPK dose by one-half without yield loss. As seems evident from the effect of an annual application of crop residue or triannual application of manure, the effect of organic matter is a more limiting factor in the Sahel than in the more humid zones. Although the limited availability of large quantities of organic residues poses restrictions on its use, the excellent residual effect of heavy applications of manure suggests the use of the limited quantities on selected fields on a rotational basis.

In Table 1 the results of the first 2 years of a long-term trial at the ICRISAT Sahelian Center at Sadore, Niger, are summarized. The validity of the previous conclusions is confirmed by the response of the treatments in the Sadore trial. In the first year, 2 tons of crop residue were brought in from elsewhere, but the effectiveness of crop residue in the Sahel to boost crop yields cannot be overemphasized. The use of crop residue is encouraging. If properly fertilized in year one, the system could produce adequate amounts of straw both for domestic use and direct return to the soil.

In previous years, IFDC's scientists have used response curve experiments to estimate the performance of various fertilizer sources or management practices. Other nutrients not tested were applied in adequate amounts. However, as the scientists aim to better characterize the environments for which they are tailoring fertilizer management practices, it is important to gain a better understanding of the nutrient response and true nutrient status of

Table 1. Grain Millet Response to Fertilizer Sources in a Long-Term Fertilizer Trial at Sadore, Niger

No.	Treatments*	Millet Grain Yield 1987	1988	Mean	**
		(kg/ha)			
1	Control	449	479	464	d
2	SSP	877	855	866	c
3	TSP	928	838	883	c
4	SSP + N + K	857	1,071	964	b
5	NPKS + Mg + Zn	834	1,077	956	b
6	NPKS + Ca	833	1,130	982	b
7	Crop residue (CR)	696	778	737	c
8	Manure/3 years	1,074	1,035	1,055	a
9	NPKS + Mg + Zn + Ca	1,125	974	1,049	a
10	NPKS + Mg + Zn + CR	1,235	1,241	1,238	a
	Sd			280	
	Mean			890	
	CV (%)			31	

*Lime (Ca) and manure in 1987 only at 0.5 and 10 tons, respectively, for 3 years. Crop residue (CR) annual 2 tons or actual.
**Means with same letter are not statistically different (Prob. 0.05)

experimental sites in the region. A series of experiments were designed to study the interactions of the principal nutrients currently known to be critical in most of West Africa: NPK and sulfur. The experiments are a component of WAFMEN and were conducted by IFDC scientists in collaboration with national scientists.

Response to sulfur in the humid and subhumid regions of West Africa has been demonstrated previously (*IFDC Annual Report, 1987*). Data in Figures 2 and 3 show that the response to sulfur may depend on the nutrient balance in the soil. In the humid zone of Ashanti, Ghana, the response of maize to nitrogen was hardly affected by the addition of sulfur at intermediate levels of phosphorus (40 kg). In the absence of phosphorus, there was no response to sulfur; however, at high phosphorus application levels there was a positive response to sulfur. A similar differential response to sulfur was observed in the subhumid zone of Togo (Figure 3).

Although a response to potassium is rarely reported in West Africa, it would be prudent to give more attention to this element, particularly in the humid tropics. As is demonstrated in Figure 4, a response to potassium was obtained at combinations of phosphorus and nitrogen. It is well known that potassium is a mobile element, especially in soil systems dominated by 1:1 lattice clays that are easily leached in environments with rainfall in excess of 1,800 mm. Although reports from the savanna region of northern Nigeria had in the past played down the importance of potassium, the response to this nutrient was dramatic in 1988 (Figure 5).

The data shown above are but a small sample of the wealth of information that has been collected within WAFMEN over the past 8 years. The data are computerized in a data base with inputs from on-farm trials and 18 experimental stations spread over 14 collaborating countries in the region. The information is available upon request and can be consulted at the IFDC office in Lomé.

A major goal of IFDC is to promote the development of national systems capable of establishing fertilizer research and extension programs. WAFMEN continues to be the major regional framework of interaction with national research and extension organizations. WAFMEN's major goal is to develop the capabilities of national scientists to undertake fertilizer research and acquire skills in field experimentation, data collection and analysis, soil and plant analysis, and formulation of appropriate priorities and recommendations for fertilizer use. At the annual WAFMEN meeting held in Lomé in February 1988, it was unanimously agreed that research network

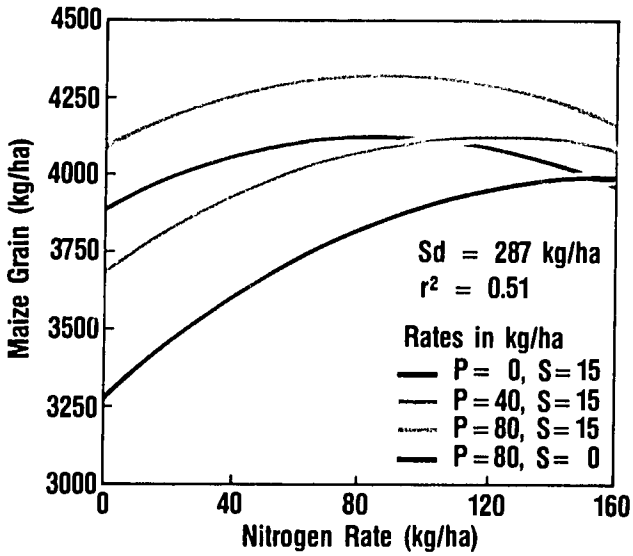


Figure 2. Crop Response to NPKS Fertilizers, Humid Area in Ghana.

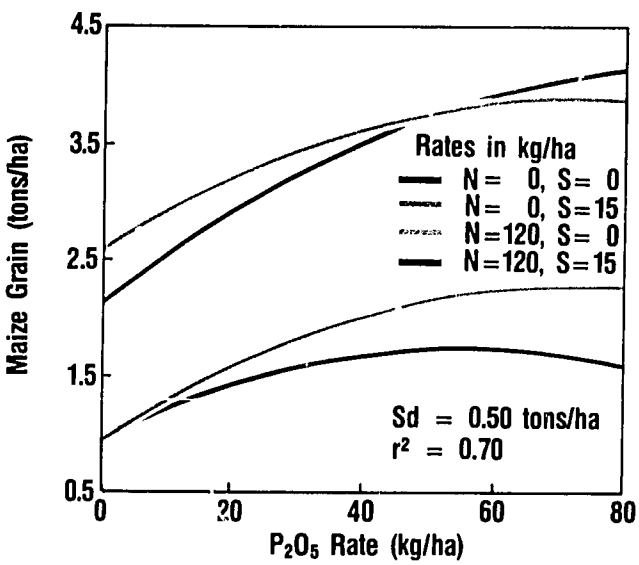


Figure 3. Crop Response to NPKS Fertilizers, Subhumid Area in Togo (Tchitchao).

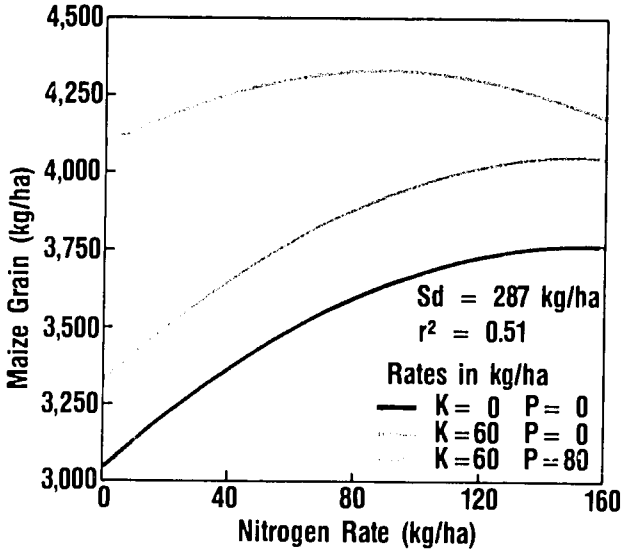


Figure 4.
Crop Response to NPKS Fertilizers, Humid Area in Ghana.

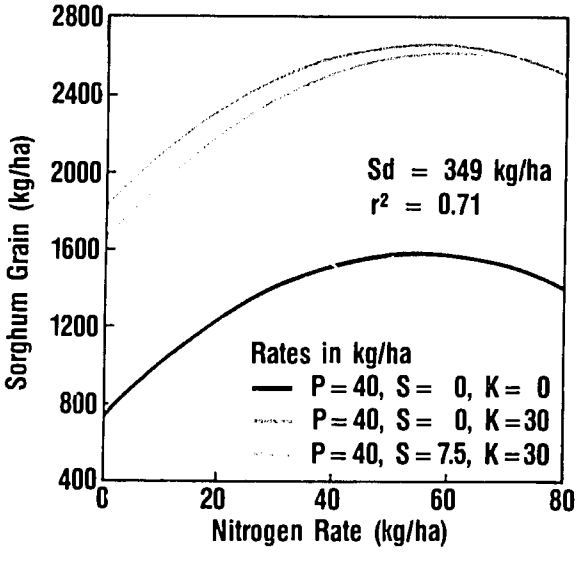


Figure 5.
Crop Response to NPKS Fertilizers, Savannah Region in Nigeria.

should expand its membership to include extension workers. The involvement of extension personnel is critical in the on-farm validation of research-station data accumulated over the years.

IFDC's scientists have demonstrated in laboratory and field studies the excellent residual effectiveness of phosphate fertilizers applied to the different soils of West Africa. The scientists have continued their research to develop a phosphate fertilizer management system that would take advantage of this phenomenon. In order to develop a viable system, it is important to be able to quantitatively describe the residual effectiveness of phosphate fertilizers. To determine this effectiveness, the increases in yield of previously fertilized plots are compared with yields from plots to which a fresh application of phosphate fertilizer was made for that season, through the Residual Effectiveness Index (REI).

The REI values for trials at Amoutchou and Tchitchao in Togo are summarized in Table 2. In general, REI was greater than 0.60, which indicated that a farmer who adds phosphate fertilizer to his soil can expect to obtain at least 60% of maximum yield the next year if for any reason he fails to reapply the fertilizer. The higher the inherent fertility of the soil, the higher is the REI for water-soluble fertilizers as is shown by SSP data at Amoutchou.

IFDC's scientists have continued to investigate the fate of nitrogen applied to crops. Data in previous years have shown that losses of applied nitrogen are high in the Sahel and that a split application of nitrogen fertilizers should be practiced. The data in Table 3, showing the ^{15}N recovery from either first split or second split application of urea, indicate the greater efficiency of the second split application of urea. In addition, most of this nitrogen is in the grain where there is potential to improve the nutritional quality of the grain. IFDC's ultimate goal is to promote increased and efficient use of fertilizers in order to produce more food and arrest soil degradation. IFDC's researchers have adopted the philosophy that farmers must become involved in the process of generating fertilizer technology through on-farm research if the goal is to be attained. As a result, the farmer-participatory, on-farm research in the village of Gobery in Niger involving 20 farm families was continued in 1988.

Residual effects and increases in millet yields from annual applications of 30 kg P_2O_5/ha and 30 kg N/ha were observed in 1988 (Figure 6). These results were of the same magnitude as in the previous 2 years although yields were lower. The reasons were poor plant establishment due to sandblasting and unusually high rainfall in Niger in 1988 that led to the incidence of

Table 2. Residual Effectiveness Index (REI) for Different Phosphorus Fertilizer Sources in Togo (1988)

Phosphorus Source	REI[a] Amoutchou	REI[a] Tchitchao
PR Annual	0.65	0.61
PR Basal	0.58	0.78
PAPR (50%)	0.64	0.67
SSP	0.89	0.66

a. $\frac{\text{Increased Yield of Residual Treatment}}{\text{Increased Yield of Applied SSP}}$

Table 3. ^{15}N Recovery in Sorghum Plant and the Soil at Two Different Times of Nitrogen Application, Gaya, Niger, Rainy Season, 1986

Time of N Application	Grain	Stover	Total Plant	Total Soil	Total Recovery
	(%)				
First split	8.43	15.53	25.75	40.25	66.00
Second split	19.20	13.60	33.13	34.92	68.05
Mean	13.82	14.57	29.44	37.58	67.03

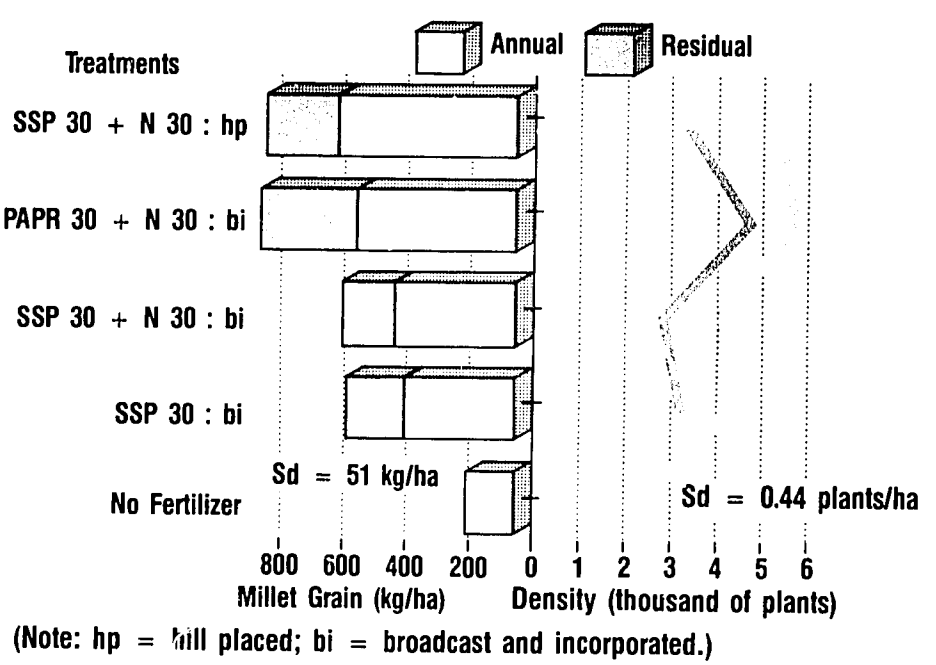


Figure 6. Farm-Managed Trials, Gobery, Niger, 1988.

diseases. Results from 1988 and previous years demonstrated the influence of plant density and method of fertilizer application (broadcast and incorporated or hill placed) on the response by millet to fertilizer.

Studies undertaken by ICRISAT showed that over the 5 years that IFDC and ICRISAT have worked with farmers in Gobery, fertilizer consumption has risen from about 1 tpy to over 100 tpy. Increased yields from fertilizer use have an additional advantage in terms of sustainability of agriculture. At the beginning of the 1988 cropping season, traditional plots where no fertilizers were applied had on the average 0.5 t/ha of crop residue on the soil surface. Fertilized plots had about 2 t/ha of crop residue, which served as a source of nutrients and as mulch.

The success of Gobery encouraged the Government of Niger to seek funds from USAID to transfer the Gobery experience to other locations. This project was directly under the Extension Service of the Nigerien Ministry of Agriculture. An IFDC extension agronomist was assigned to the service. The results to date indicate that where participating farmers applied fertilizers, the yield increase ranged from a low of 17% in the dry north to 100% in the south.

Fertilizer Investment for Soil Fertility Restoration

Background and Objectives

The soils of West Africa are generally low in fertility and fragile. Small farmers have traditionally coped with these problems by resorting to bush fallow rotations, which have permitted low but relatively stable levels of crop production. However, the bush fallow system is becoming less feasible in the humid zone and has been replaced by

continuous cropping of fertility-depleted soils in many areas in the Savanna and Sahelian zones. There is an urgent need to develop and test systems of soil management that will increase crop production substantially at the village level and at the same time protect the natural resource base for agriculture in the region.

The Soil Fertility Restoration Project (SFRP) seeks to identify and characterize villages in pilot areas where there is considerable potential to use fertilizers on a sustainable basis. It will assess the impact of various soil amendments and fertilizer options, especially phosphates, on crop production, soil fertility restoration, the socioeconomy of selected villages, and the evolution of farming systems. The SFRP will ensure that recommended investment strategies in soil fertility restoration and maintenance will take into consideration factors that promote or impede the access of women to techniques to improve soil fertility. A key initial input is the timely provision of fertilizers to boost the crop yields in the experimental villages and thereby contribute to increased household incomes for small farmers.

The specific activities for the first 2 years of implementation are as follows:

1. Selection of four pilot areas in contrasting environments (rainfed humid, rainfed savanna, rainfed Sahel, and irrigated lands), where crop production and soil fertility may be significantly increased and maintained through the adoption of soil amendments and strategies for fertilizer use;
2. Collection of ecological and socioeconomic baseline data in the four selected areas;
3. Establishment of pilot projects in the four selected regions in collaboration with national programs to field-test soil amendments and fertilizer use strategies;
4. Training of the necessary national program personnel to implement and monitor the pilot projects and collect the necessary agronomic and socioeconomic data to evaluate the projects and their impacts.

A farmer from the Maradi pilot area in Niger uses animal traction for early weeding of a fertilized millet crop. IFDC-Africa is conducting research designed to restore the fertility of West African soils and, thus, increase crop yields.

Baseline Surveys

Exploratory socioeconomic surveys were conducted to select the pilot areas (rainfed) and two villages (one experimental and one control) within the pilot areas. Detailed surveys involving interviews with about 120 farmers in each pilot area were conducted.

Criteria that were used for selecting these villages included crops and cropping systems, soils, availability of extension services, demographic variables, land tenure, physical environment, previous fertilizer use, patterns of migration, storage facilities, and sociocultural environment. Extensive interviews with the chiefs of both villages were conducted by a rural sociologist. These interviews identified key agricultural issues, problems, and achievements in each village. During the initial year of the project, working relationships were established with the national collaborators.

In-Country Soil Classification and Agronomic Research

The soils of the pilot areas—Kumasi in the Ghana humid zone, Dapaong in the savanna zone of Togo, and Maradi in the Sahelian zone of Niger—were classified and analyzed. Pertinent data on the farming systems and agronomic practices of the three pilot areas were obtained. Trials were conducted in Ghana and Niger to evaluate up to five fertilizer treatments in four to five villages in each pilot area to provide guidelines for fertilizer application for maize and millet in 1989.

In Ghana the combination of urea, potassium chloride, and SSP appeared to be the most promising treatment while urea and SSP gave best results in Niger. Short in-country training programs on the collection and management of data were conducted for national research and extension personnel in the pilot areas, and workshops with in-country coordinators to monitor and plan project activities were organized regularly.

East and Southeast Africa Fertilizer Research Program

Introduction

The East and Southeast Africa Fertilizer Research Program started in 1987 continued to gain momentum in 1988. New countries and organizations added to the East and Southeast Africa Fertilizer Management and Evaluation Network in 1988 included Malawi (Ministry of Agriculture), Tanzania (Agricultural Research Organization), Ethiopia (Institute of Geological Surveys), Kenya (University of Nairobi, Department of Geology), and Uganda (Tororo Industrial Chemicals and Fertilizer Limited).

Partially acidulated phosphate rock (PAPR) (25% and 50%, sulfuric acid-based material) prepared in 1988 was from the Dorowa phosphate deposit in Zimbabwe, Minjingu deposit in Tanzania, and Chilembwe deposit in Zambia. Field trials with these products are presently underway in Zimbabwe, Zambia, Tanzania, Kenya, Ethiopia, and Uganda.

Preparation of Experimental Fertilizer From Indigenous Phosphate Ores

Two important components of the program were the determination of the characteristics of phosphate ores in the region and the preparation of experimental products for agronomic evaluation. As a result of a previous workshop on East and Southeast Africa fertilizer minerals (Lusaka, Zambia, in 1987), a number of country participants provided IFDC with samples of phosphate ores for use in the program. In some cases the ores were converted to products for agronomic testing in the network. Ores from Uganda, Zimbabwe, Tanzania, and Zambia received emphasis because of availability. The products made were single-nutrient materials containing phosphorus only—ground rock, SSP, and PAPR. Where needed. the run-of-mine ore was beneficiated prior to chemical conversion. Currently, the Uganda and Zambia ores are not mined commercially whereas Tanzania and Zimbabwe ores are. Each ore has specific characteristics that affect its use; these are being evaluated.

The Zimbabwe, Tanzania, and Uganda ores were used "as received" because they had been beneficiated. The Zambian ore required beneficiation, which was done at IFDC in laboratory- and pilot plant-scale equipment. All rocks after beneficiation were acceptably high in grade (>29.5% P_2O_5) and suitable for PAPR production. One measure of reactivity is the P_2O_5 solubility in a neutral ammonium citrate solution. Only the Minjingu rock from Tanzania is considered high in reactivity (6.0% citrate-soluble P_2O_5). The other samples are low in reactivity based on citrate-soluble P_2O_5.

The Chilembwe, Zambia, sample "as-received" contained 19.6% P_2O_5 with silica (42%) being the major diluent. The original ore is low in iron oxide (1.5%), aluminum oxide (1.2%), and magnesium oxide (0.4%). A laboratory-scale beneficiation study was carried out comparing three flotation routes. Direct anionic phosphate flotation gave the best results; it yielded a concentrate containing 37.2% P_2O_5 and 4.2% silica. Based on this initial study a large sample was processed in the pilot plant to be used for PAPR production. No attempt was made to optimize the pilot-plant operation.

Field Trials at Matopos, Zimbabwe, Involving Both Nitrogen and Phosphate on Sorghum

First-season results of studies at Matopos indicated a significant response to applied nitrogen in terms of sorghum grain yield and suggested that broadcasting (plus incorporation) ammonium nitrate in two equal splits may be the most effective way of applying nitrogen at low rates (30 kg/ha). At higher rates (60 kg and 90 kg nitrogen/ha) the effects of banding or broadcasting urea and AN and point placement of urea using urea supergranules were not significantly different. Phosphate studies at Matopos also indicated a significant response to applied phosphate in terms of sorghum grain yield, and there were no significant differences between the three phosphate sources used, i.e., SSP, triple superphosphate (TSP), and Zimbabwe phosphate rock (50% partially acidulated with sulfuric acid). Low rates (20 kg P_2O_5/ha) were not effective while higher rates (40 kg and 60 kg P_2O_5/ha) significantly increased grain yield.

Field Trials at Kasama, Zambia

The Soils Productivity Research Programme of Zambia, with support from the Norwegian Agency for Development (NORAD), is carrying out field trials comparing IFDC-produced PAPR and phosphate rock with two other sources of phosphate. The trials using maize and finger millet as the test crops were established in 1987 and are in their second season. The trials are located at Kasama, Zambia, about 900 km north of Lusaka on two soil series—Mufulira and Konkola. The four sources of phosphate being evaluated are Japanese fused magnesium phosphate, 50% PAPR (Chilembwe Zambia PR), TSP or ground rock phosphate, and Zambia-fused magnesium phosphate.

Results for the 1988 season indicate good performance of PAPR on both soils. When PAPR was applied at 60 kg P_2O_5 per hectare, maize yield was the highest on both soils. This may be due to the sulfur included in the PAPR but missing in the TSP. On the Konkola soil the yield was 3.7 tons, and on the Mufulira soil it was 5.2 ton/ha. TSP at 60 kg of P_2O_5/ha produced a yield of 3.4 tons of maize per hectare on the Konkola soil.

Dr. Obed I. Lungu, Senior Lecturer in Soil Science, College of Agricultural Sciences, University of Zambia, and Dr. Henry Ssali, IFDC Soil Scientist, examine maize grown on PAPR field trials on a University of Zambia farm. This research is being conducted under the East and Southeast Africa Fertilizer Research Program being coordinated by IFDC.

Technical Assistance in Africa

Burundi

Progress continued in assisting the Department of Mines and Geology to assess the Matongo phosphate ore in Burundi for possible fertilizer production. The technical and preliminary economic merits of using the ore for producing SSP, PAPR, organic fertilizers (Bioearth and Biolife), and for direct application are under evaluation. The ore must be upgraded (increase in P_2O_5 content and removal of iron oxide) to render it suitable as a feedstock for phosphate fertilizer production. Based on a subsample provided to IFDC, a scheme was developed to wash and scrub to reduce slimes and magnetically separate the iron to yield a high-grade concentrate (>32% P_2O_5 and 1% iron oxide). A report on the project was presented to the World Bank and officials with the Department of Mines and Geology in late 1988. Plans were made for securing a 12-mt sample of washed ore from Burundi for further tests in 1989 at IFDC. All products will be shipped to Burundi for agronomic evaluations. Organic fertilizers will be produced in Burundi.

Malawi

At the request of the Ministry of Agriculture, Government of the Republic of Malawi, IFDC conducted an evaluation of the fertilizer marketing system in Malawi. The objectives of the study were to (1) assess the efficiency of the existing fertilizer marketing system in meeting the fertilizer-related needs of Malawi farmers on a cost-effective basis, (2) recommend improvements in retail fertilizer marketing practices, and (3) determine the need and scope for private-sector involvement in fertilizer marketing. IFDC, in collaboration with two Malawian counterparts, conducted the study during October-December 1988.

The fertilizer market in Malawi is comprised of two channel systems. The Government, through various Government agencies, serves the smallholder fertilizer sector. Various private-sector entities serve the estate sector. Fertilizers are sold in the smallholder sector at subsidized prices, and estate sector sales are on a cost-plus basis. One of the most significant recommendations in the study was that the Malawi Government encourage private-sector involvement in all fertilizer marketing.

Under the recommended marketing system, the entities involved in fertilizer marketing would operate on a commercial basis. As a result of improved marketing planning and performance of the marketing functions, fertilizer use in Malawi is expected to increase from 120,000 product tons in 1988 to 206,000 tons in 1995, a compound growth rate of over 8% per year.

Nigeria

Review of Distribution and Demand

At the request of the World Bank, IFDC conducted a review of the fertilizer marketing system in Nigeria. The study's two principal areas of focus were (1) the estimation of fertilizer demand and (2) evaluation of the operating efficiencies of the fertilizer distribution system.

All activities related to fertilizer marketing in Nigeria are performed by the Government, including product selection and procurement, distribution, pricing, and extension services. The IFDC study team was assisted by two representatives of the Fertilizer Procurement and Distribution Division of the Ministry of Agriculture and concluded that the existing distribution system is efficiently structured. Virtually all imported fertilizer is offloaded directly from ships to trucks for direct movement to inland storage depots. This procedure minimizes the number of handling and storage operations and associated losses. It also allows for direct movement of products to the primary distribution points in the country; thus, overall transport costs are reduced.

Fertilizer demand in Nigeria was analyzed. Particular attention was given to fertilizer and crop price relationships, and projections of future levels of fertilizer consumption were developed. Fertilizer prices are heavily subsidized in Nigeria, up to 80% for some products. Meanwhile, crop prices are not controlled and fluctuate with changes in market conditions. As a result, the financial incentive for farmers to use fertilizers varies considerably by crop and time period.

Fertilizer use in Nigeria was expected to decline in 1987/88 due to supply shortages. During 1988-93, consumption of nitrogen, phosphate, and potash is expected to increased by 5.3%, 7%, and 3.6%/year, respectively. Nitrogen, phosphate, and potash use is expected to total 165,000 tons, 129,000 tons, and 61,000

tons of nutrient, respectively, in 1993. These estimates assume a continuation of existing policies on fertilizer subsidy by the Government and availability of funds for timely procurement of fertilizers, which has been a problem in the past.

Assistance to NAFCON

Nigeria's new fertilizer complex owned by the National Fertilizer Company of Nigeria Limited (NAFCON) is designed to produce ammonia, granular urea, diammonium phosphate (DAP), and urea-based NPKs. The facility began operation in 1987. The ammonia/urea unit is export-oriented while the DAP/NPK granulation unit is geared to supplying the local market.

During 1988 IFDC provided assistance on an intermittent basis to M. W. Kellogg, a joint venture partner in the NAFCON project, on behalf of the NAFCON DAP/NPK plant. The IFDC assistance was designed to examine alternative ways to produce NPK 15-15-15, the most popular NPK product in Nigeria. The current method of production is based on the use of urea as the primary source of nitrogen. This has led to problems in processing and product quality largely due to the presence of urea, the use of an abrasive sand filler, and the humid plant environment.

An alternative method proposed for producing a product containing less urea and no inert filler is based on the use of ammonium sulfate as the primary source of nitrogen. In addition to alleviating most of the problems with processing and product quality attributed mainly to the presence of urea, the ammonium sulfate-based alternative offers the added benefit of providing agronomic sulfur in the NPK.

Because of the possibility of excessive corrosion of certain process equipment, especially the existing NAFCON preneutralizer, when neutralizing sulfuric acid to form ammonium sulfate in the existing process, pilot plant-scale preneutralization studies were performed by IFDC to determine the optimum operating criteria and level of corrosion that could be expected.

These data and information gathered by an IFDC production specialist during a visit to the NAFCON plant were used to prepare a process design modification for NAFCON's consideration. Additional short-term plant-scale demonstration testing of the proposed new process scheme was recommended to ensure that the proposed changes and sulfur-containing NPK product would meet NAFCON's expectations.

Bulk-Blending Project in Kaduna

Agri-Chemicals Limited (ACL) of London, England, is developing a fertilizer bulk-blending project in the state of Kaduna in Nigeria. The projected output of the blending plant, to be operated by Fertilizers and Chemicals Limited of Lagos, is 50,000 mt of product in the first year of operation (1989). Production is expected to increase to about 72,000 mtpy over a 3-5 year period. The project will use imported raw materials supplemented with granular urea, and perhaps DAP, produced in the new Nigerian plant, NAFCON located near Port Harcourt.

During the course of this project, IFDC provided ACL with basic technical data relative to the design and operation of the plant. Furthermore, IFDC, in two separate studies, developed the expected factory-gate production cost for a number of bulk-blend formulations that were being considered for production. These cost estimates were based on site-specific investment data provided by ACL and raw material cost and transport data developed by IFDC. These data on factory-gate production costs can be used as a reference in evaluating the long-term feasibility of local blending compared with other fertilizer supply alternatives.

Tanzania

The Finnish Department for International Cooperation (FINNIDA) contracted with IFDC to participate with a team in Tanzania assembled to conduct an economic study to determine the potential for continuing the mining operation of the Minjingu Phosphate Company (MIPCO). Specifically, the team's mission was to:

1. Identify in detail the external and internal constraints restricting the Minjingu Phosphate Company's production capacity.
2. Develop plans for elimination of the constraints.
3. Investigate alternative courses of action and anticipated economic outcomes and suggest a realistic course of action, which will produce optimal economic results.

Markets—The major consumer of Minjingu phosphate rock concentrate is Tanzania Fertilizer Company (TFC) at Tanga. The TFC plant established in 1972 also produces nitrogen as ammonium sulfate and various bulk blends of NPK fertilizers. Beginning in 1982, MIPCO began supplying Minjingu phosphate

rock concentrate to TFC rather than imported rock to save foreign exchange. Since 1982, 86,961 tons has been used to manufacture SSP and TSP. Peak production at TFC occurred in 1981 when 69,031 tons of product was produced; this included 23,404 tons of TSP.

A secondary potential market for Minjingu phosphate rock concentrate is for direct application on cropland in Tanzania and Kenya. These markets would have to be developed. In the five northern regions of Tanzania—Arusha, Dodoma, Kilimanjaro, Singida, and Tanga—which are within 450 km of Arusha, sales of Minjingu phosphate rock concentrate could reach 25,000 tons by 1995. Kenya grows substantial quantities of coffee and tea. These crops provide a potential market for approximately 11,000 tons/year of Minjingu phosphate rock concentrate by 1995.

Minjingu is also supplying a limited amount of phosphate rock concentrate to an SSP plant in Thika, Kenya.

The Phosphate Reserves—Phosphate resources at Minjingu exist as soft rock and hard rock ore types. Based on the latest reserve study and MIPCO production data, approximately 273,000 tons of soft phosphate concentrate can be produced under the current mine plan using the existing beneficiation plant. This is not considered an adequate supply of phosphate rock. Additional soft rock resources exist around the immediate areas of the mine, but the quantity has not been determined. The phosphate contents of the proven soft ore average about 23% (P_2O_5 basis). Beneficiation could raise the phosphate content of the concentrate to approximately 30%. The soft rock is considered highly reactive and suitable for direct application, especially for long duration crops and on acid soils. Field trials on acid soils have shown good agronomic and economic yield responses with soft rock.

The hard Minjingu phosphate rock is not as reactive as the soft rock and probably cannot be beneficiated by the present equipment. Grinding of the hard rock would be required if used for direct application. Field trials to measure crop response with hard rock have not been conducted. About 10 million tons is in the form of hard phosphate rock.

The study found that the MIPCO operation contributes to the economy of the country through import substitution, export earnings, and contributions to agricultural development.

Togo

The Office Togolais des Phosphates (OTP) in Lomé, Togo, has an ongoing contract with IFDC for technical assistance for acquiring, installing, and operating a beneficiation pilot plant to be located at their phosphate rock processing facility in Kpéme, Togo. IFDC is to provide process equipment specifications, electrical and piping specifications and bill of materials, schematic drawings of electrical circuits, layout drawings of equipment, supervision of plant installation, personnel training, and startup assistance. The plant is scheduled for completion in late 1989 and will be used by OTP to test new local ore types and/or deposits for future production. These ore types and/or deposits are expected to require beneficiation in order to increase the phosphate grade to commercial levels. The new pilot plant will be used to gather information needed to modify OTP's existing plant to process these ore types.

The invitation-to-bid document for the process equipment was prepared by IFDC. After the vendor bids were analyzed, a contract for equipment supply was signed by OTP with a U.S. company early in 1988. The equipment was inspected by IFDC and shipped to Togo in late November. In early December a visit to the OTP site was made by a team of IFDC engineers regarding installation of the equipment in a new building being constructed by OTP.

Uganda

An IFDC engineer was requested by USAID-Uganda to advise on the use of Sukulu Hills phosphate ore in Uganda as a raw material, especially in a low-cost scenario such as directly applied finely ground rock on acid soils. Sukulu Hills in eastern Uganda is a well-known phosphate deposit, which was actively mined, beneficiated (upgraded), and processed to SSP until the early 1970s. The original plant is now in a state of disrepair, and a considerable investment is required if operation is to resume. In 1984 IFDC participated in a sizeable study that was performed by Bearden-Potter Corporation, U.S.A., for the Government of Uganda to determine the technical and economic feasibility of reopening and rehabilitation of the mine, beneficiation, and fertilizer plants, but at a level of 10 times the original capacity (50,000 mt P_2O_5/year). The products would be SSP, PAPR, and ammoniated phosphate (4-18-0). At this time funding for the project has not been identified.

USAID was informed that the run-of-mine ore is low in grade ($\cong$13% P_2O_5) and has low reactivity; thus, its use for direct

application is very questionable. Its relative agronomic effectiveness even on acid soils is expected to be low but must be determined by agronomic trials. These trials are underway with IFDC's assistance under the East and Southeast Africa Fertilizer Research Program. USAID was advised to wait for the agronomic results of these trials, which were initiated in late 1988 with Makerere University, before establishing a policy for using the Sukulu Hills deposit.

USAID was also interested in using agricultural limestone for southwestern Uganda, which has very acidic soils. According to the Uganda Development Corporation there are substantial reserves in western Uganda at Hima, which could be used as agricultural limestone. All limestone being mined there now and elsewhere is used for cement, which is in short supply. It was recommended that a feasibility study be made for production of agricultural limestone in Uganda.

IGADD

During 1988 a regional fertilizer policy study was conducted by IFDC for six member countries of the Intergovernmental Authority on Drought and Development (IGADD)—Djibouti, Ethiopia, Kenya, Somalia, Sudan, and Uganda. The goal of the study, funded by USAID, was to develop a fertilizer policy for the entire IGADD region. IGADD is at present implementing a plan of action targeted toward alleviating short-run drought emergencies, laying the foundation for drought recovery and development in the mid-term, and implementing ecologically balanced long-term development programs. To attain these goals, the plan of action calls for the establishment and improvement of food security and early warning systems for famine in its subregion.

The study determined that eight measures regarding fertilizer policy should be implemented. They include: a stable policy toward agricultural production, a sound policy on fertilizer imports, a policy on the import and use of high-analysis fertilizer, a policy to increase fertilizer research in all IGADD countries, a policy to accelerate research on the development of irrigation technologies, a sound and stable policy regarding the valuation of domestic currency, a policy toward fertilizer production, and a policy supporting stable markets where farmers can be assured of a place to sell their crop produce.

Growth Maintained in Asian Fertilizer Sector

Asia Fertilizer Situation

Consumption

Prior to 1980 North America was the leading fertilizer-consuming region of the world. Since then Asia has taken over that role. In 1980 Asia accounted for 25% of the total world fertilizer consumption; by 1988 Asia's share for all products increased to 33%, with nitrogen consumption climbing to about 41%. Also, Asia experienced more than 6% annual growth in its total fertilizer use during the 1980-88 period.

Total fertilizer use in Asia increased from about 28 million tons in 1980 to 47 million tons in 1988. Asia's total fertilizer consumption increased more than eightfold—from 3.36 million tons in 1960 to 27.95 million tons in 1980. During the same period nitrogen, phosphate, and potash consumption increased from 1.87, 0.83, and 0.65 million tons in 1960 to 19.55, 5.89, and 2.52 million tons in 1980, respectively. From these data, it is obvious that nitrogen use grew much faster than phosphate and potash during the 1960-80 period. This trend continued in the 1980s as well. For example, nitrogen fertilizer use increased by 12.05 million tons from 19.55 million tons in 1980 to 31.60 million tons in 1988. Against this, phosphate use increased by 5.1 million tons and potash use by 1.7 million tons.

Several factors seemed to have contributed to this rapid growth in total fertilizer consumption, in general, and in nitrogen consumption, in particular. Notable among these are (1) availability and diffusion of fertilizer-intensive high-yielding varieties of wheat, rice, and maize; (2) expansion of irrigated areas; (3) high degree of government commitment and involvement in the fertilizer sector; (4) rapid increase in domestic nitrogen production capacity; and (5) stable and profitable pricing environment created through a balance of crop price support and fertilizer subsidy programs.

Production

Asia's fertilizer production followed a pattern similar to that of its fertilizer consumption. Total fertilizer production increased from a small base of 1.2 million tons in 1960 to 7.8 million tons in 1970 and 22.8 million tons in 1980. Another 16.6 million tons was added during the 1980s. With 39.4 million tons of total production in 1988, Asia accounted for about 26% of the total world production. Asia also contributed more than 50% of the increase in total global production and experienced a 6% annual increase in total production during the 1980s.

Nitrogen production increased from less than half a million tons in 1960 to about 13 million tons in 1980 and 28.6 million tons in 1988. This doubling of nitrogen production in the 1980s was achieved through several measures. Notable among them are incentive prices, conducive policy environment, availability of natural gas, and the desire to achieve food security through increased fertilizer use.

Phosphate production increased from less than 1 million tons in 1960 to 4.6 million tons in 1980 and 8.8 million tons in 1988. Likewise, potash production also increased by a small quantity—from 0.44 million tons in 1970 to 2 million tons in 1988, because Asia lacks potash resources.

Asia experienced acceleration in its fertilizer production during the late 1970s and early 1980s. High costs of imported fertilizer during the mid-1970s put pressure on the policymakers to create a suitable policy environment for increased fertilizer production. Further, through suitable pricing policy measures, many Asian countries protected their fertilizer industry during the declining and low fertilizer prices of the mid-1980s.

Excerpted from *Global Fertilizer Perspective, 1960-95: The Dynamics of Growth and Structural Change*, by Balu L. Bumb, IFDC, 1989.

Introduction

IFDC's involvement on the Asian scene during 1988 consisted of nitrogen, phosphate, and sulfur research, technical assistance activities, and a continuing national program in Bangladesh. The nitrogen research component focused on the Center's continuing efforts to improve the efficiency of urea through the modification for deep placement, coatings, and the addition of urease inhibitors. The primary objective of these three treatments is to reduce nitrogen losses via ammonia volatilization and/or leaching. The ultimate goal of field research in Indonesia is to improve the economics of phosphorus use by introducing a lower cost per unit yet agronomically effective phosphate fertilizer. Sulfur research in Thailand focused on comparing alternative methods of supplying plant nutrient sulfur with urea fertilizer to rainfed rice in a rice-soybean cropping sequence.

Technical assistance activities were carried out in China, India, Israel, Malaysia, and Saudi Arabia. The national program in Bangladesh continued with its goal of increasing fertilizer use through the development of a cost-effective and responsive fertilizer distribution system.

Research Activities

Nitrogen Research

Deep Placement of Urea Supergranules

The size of each USG permits its deep placement in the soil, into a zone where losses are minimized. In prior studies it was estimated that village-level briquetting of prilled urea as a means of making USG would add no more than 10% extra cost when compared with prilled product. This finding was based on work done with a modified briquetting machine originally made in the People's Republic of China. With modifications the machine can produce 250 kg/h of 1-g USG. The concept involves locating a machine in a regional or village warehouse where urea is readily available. Urea fines or off-grade materials can be reclaimed or prilled materials can also be made into briquettes.

A computer model was developed to assess the economics of USG production using the modified briquetter scheme. A detailed case study was made for Indonesia. The model predicts the quantity of USG per machine to be made per year to cover all fixed and variable costs under different assumptions; the increase in USG cost over that of prilled urea is kept at 10%. The model can be applied to any specific situation where USG made by the modified briquetter has potential application.

Greenhouse Evaluation of Urea and DAP for Deep Placement

Two greenhouse experiments were conducted to evaluate deep-placed USG containing DAP as a source of nitrogen and phosphate for transplanted rice. The experiment conducted at Headquarters used calcareous soil. A similar experiment was conducted at the Konkan Krishi Vidyapeeth (KKV) campus, Dapoli, Maharashtra, India, using acidic lateritic soil. The results of both experiments suggest that deep placement of USG (as urea briquettes) containing the right amount of DAP (as NP fertilizer) may be a judicious choice for rainfed transplanted rice in two cases. These cases are: (1) when it is difficult to properly incorporate phosphatic fertilizer before transplanting due to agroclimatic constraints commonly experienced in rainfed (monsoon) areas and nonavailability of suitable implements on fields of small rice farmers as it is today in India and (2) for rice soils with high phosphorus-fixing capacity. Further research under field conditions is needed to verify this finding.

Field Trials With USG in India

Through collaboration with KKV and Indian Farmers'

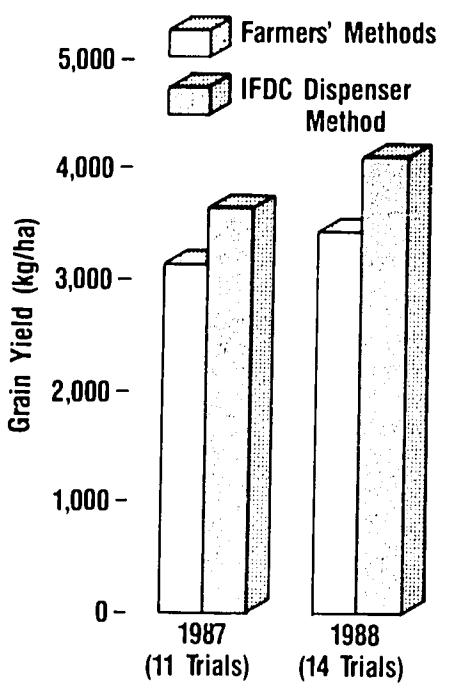


Figure 7. Yield Response of Rainfed Transplanted Rice-USG (IFDC dispenser method) and Prilled Urea (farmers' methods) at 38 kg N/ha in Farmer-Managed Trials in the Konkan Region, Maharashtra State, India.

Philippine field workers transplant rice seedlings. The IFDC/IRRI collaborative project, marking a decade of progress in 1988, has concentrated on the reduction of nitrogen losses on flooded rice.

Fertiliser Cooperative Ltd. (IFFCO), New Delhi, India, an IFDC soil scientist continued evaluation of the IFDC Dispenser Method of hand deep placement of USG during line transplanting for rainfed transplanted rice in India. Small Indian rice farmers in rainfed areas have limited resources, generally transplant rice at random, and can afford only a small amount of urea fertilizer. Therefore, they can benefit the most from this method of USG placement. Agronomic performance of the method of deep placement of USG was compared with that of the farmers' methods (random transplanting and split application or placement of prilled urea in the furrow immediately behind the plow during the last puddling). In 14 trials conducted during the 1988 Kharif (wet) season on the small farmers' fields using their limited skill and inputs, results continued to show the agronomic superiority of the IFDC Dispenser Method observed during the 1987 trials (Figure 7). The participating farmers harvested an average additional yield of approximately 20%, which produces an average additional income equivalent to approximately US $70/ha at the application rate of 38 kg nitrogen/ha. This technology appears to be attractive in areas where labor is abundant, nitrogen use is low, and farmer resources are limited.

Reactive-Layer Coated Urea

It has long been recognized that a nitrogen fertilizer that releases nitrogen in accordance with plant demand can improve efficiency and crop yields. Past studies had suggested that sulfur-coated urea would be a product that could release nitrogen at the required rates. However, problems such as relatively low nitrogen analysis (35%-40%), fragility of granules, uncertain nitrogen release patterns, and high cost have kept this and most other controlled release fertilizers out of the marketplace except for high-value crops. Laboratory studies at IFDC suggest that a new class of products is possible; these products may overcome some of the limitations of earlier products. These materials, called reactive-layer coated ureas (RLCU), are prepared by spraying a thin polymer coat on the urea granule. The materials produced are of high analysis (42%-44% nitrogen), durable, and release nitrogen in a predictable manner. However, they still may be of comparatively high cost.

Basic studies of the release rates were conducted with a small granule RLCU (2-3 mm diameter). The major factors controlling nitrogen release have been the coating thickness and temperature (Figures 8 and 9).

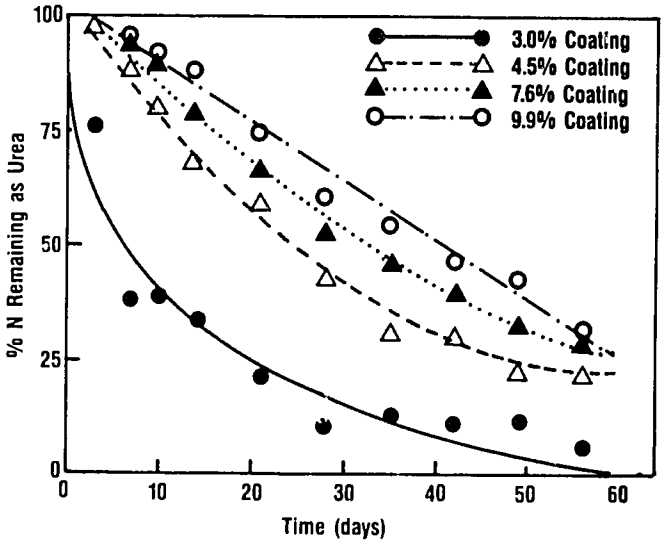


Figure 8. Effect of Coating Thickness on Nitrogen Release.

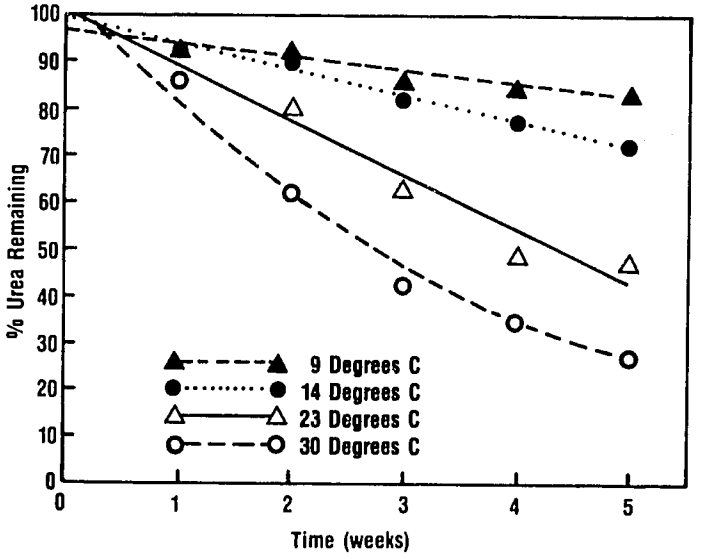


Figure 9. Effect of Soil Temperature on N Release From RLCU-34.

Release is only very slightly affected by changes in moisture and seems to be independent of the pH and biological activity of the soil. This means that the RLCU applied to a winter wheat crop will release very little nitrogen during the cool periods when the plant is dormant but will increase nitrogen release as the soil warms and the crop starts its spring growth. RLCU also be useful in soils subjc rapid movement of water ugh soil (leaching) or water-l g (which causes denitrification). In both cases nitrogen release will be slow so that only a small amount of nitrogen will be susceptible to a loss while most of the nitrogen will be protected. By contrast, very serious losses from highly soluble conventional nitrogen fertilizers could occur under identical conditions. The polymer-coated materials show very favorable release characteristics and appear to have wide applications for different crop and soil conditions.

In field studies conducted as part of the IFDC and IRRI Collaborative Program, an RLCU with 3% coating performed well, particularly when used in conjunction with a later application of urea. Since the rate of urea release from RLCU can be controlled by the thickness of the coating, this material provides a tool to determine how the release rate rather than simply curbing of nitrogen loss can alter rice grain yields. Modification of release rates may allow optimization of the plant-available nitrogen both with and without supplemental applications of urea.

Urease Inhibitors to Increase Nitrogen Efficiency

Although urea is a good nitrogen fertilizer when properly applied, it is susceptible to severe losses via ammonia volatilization when it is applied to the soil surface. Urea-nitrogen is rapidly converted by the soil enzyme urease to ammonium. If this conversion takes place at or near the soil surface, as much as one-half of the applied nitrogen can be lost under extreme conditions. Losses can be expected to be particularly high for urea applicatior s to rice, topdressings to upland crops, and in tree or plantation crops. These losses can be red' ced by chemical additives that retard the urease enzyme activity and thereby decrease ammonium concentrations at the soil surface. These chemicals inhibit the urease enzyme to varying degrees depending on their concentration in the urea and the soil conditions. The best inhibitors found to date are the phosphoric triamides.

A team of scientists was formed in late 1983 at IFDC and partially financed by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), West Germany. Work continued until August 1988. The lead scientist was from the Technische Universität München. The project involved: (1) chemical synthesis and procurement of compounds, (2) evaluation of urease inhibition by the pH-stat method, (3) urease inhibition measurement in soils without plants in the laboratory, (4) greenhouse studies at IFDC, and (5) field studies at IRRI.

Phenyl phosphorodiamidate (PPDA) was studied extensively for rice in flooded soils because it was the first compound recognized as a potent, although temporary, urease inhibitor. Its effect lasted only 3-4 days. The team was searching for a more stable inhibitor having sustained action in comparison with PPDA. Approximately 40 compounds containing phosphorus were synthesized and evaluated. Also, 10 hydroquinone derivatives were synthesized and evaluated but were found to be ineffective inhibitors.

Some work was done on specific compounds of the general class of phosphorus-containing types. One compound of particular interest to IFDC is N-(n-butyl) thiophosphoric triamide (nBTPT). Some exploratory tests were sponsored by a private firm to prepare mixtures of urea plus nBTPT and determine nBTPT stability. Addition of inhibitor to urea might be accomplished by several methods. One satisfactory method is coating nBTPT onto urea granules using a solvent. Another method consists of adding the nBTPT to urea melt followed by granulation. The products made contained 0.25% and 0.50% nBTPT by weight. The coated and granulated products were stored, and stability of nBTPT is being evaluated. Physical quality of the granular nBTPT plus urea in low-moisture (0.2%-0.3% H_2O) products compared favorably with that of urea. Further tests are planned for 1989, especially on finding an effective means to incorporate nBTPT into granular fertilizer.

Table 4. Effect of Inhibitor nBTPT on Fertilizer Recovery in the Plant and Grain Yield

Treatment	^{15}N Recovery			Grain Yield
	Plant	Soil	Total	
	(%)			(g/pot)
Control	-	-	-	28.6
Urea + 0.1% nBTPT	59.2	19.7	78.9	43.5
Urea	34.5	14.4	48.8	37.4

Greenhouse Evaluation of Urease Inhibitors

All of the triamides were very effective in reducing ammonia volatilization losses (Figure 10) from a surface application to a moist upland soil. This trial was conducted with urease inhibitor concentrations of 0.01% (100 g/ton of urea). In all cases their use substantially reduced ammonia volatilization loss, especially in the first 8 days of the experiment. The oxygen compounds (n-butyl phosphoric triamide [nBPT] and cyclohexyl phosphoric triamide [CHPT]) reduced nitrogen losses by 75%.

One of the inhibitors, n-butyl thiophosphoric triamide (nBTPT), was used in a winter wheat study conducted in the greenhouse. Urea (^{15}N enriched), either containing nBTPT (0.1%) or without inhibitor, was applied to the surface as a topdressing to the wheat. When harvested, the treatments receiving the inhibitor showed a 72% increase in fertilizer nitrogen uptake by the plant resulting in a 15% increase in grain yield (Table 4).

Experiments were also conducted with the same four urease inhibitors with flooded rice soils. The sulfur analogs did not perform as well as the oxygen analogs. This is illustrated by the disappearance of urea from the floodwater; the longer that urea remains in the water, the better the urease inhibition and the less ammonium is in the floodwater to be lost (Figure 11).

The better performance of nBPT relative to nBTPT was most evident when the urea and inhibitor were mixed into the soil (Figure 12). With incorporated fertilizers on 10 different soils, the nBTPT completely failed on half of the soils; on the other soils it was much less effective than the nBPT. This is apparently due to the fact that nBTPT must be converted in the soil to nBPT, which is the actual urease

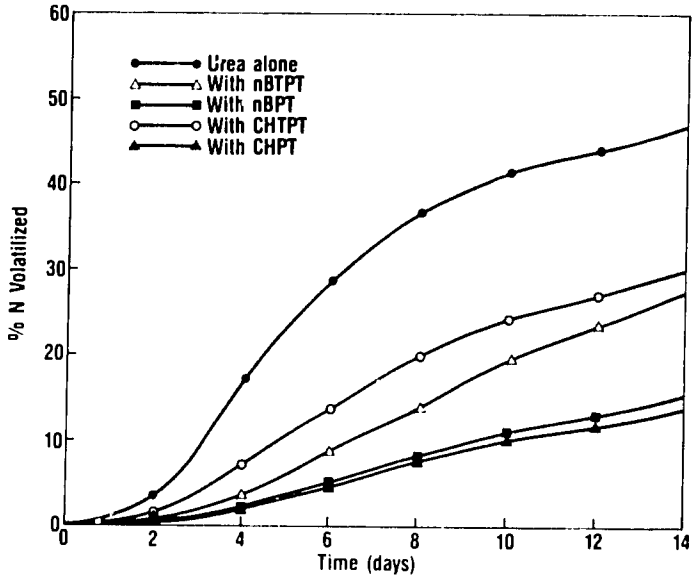


Figure 10. Cumulative Ammonia Volatilization Losses From an Upland Soil With Urease Inhibitors at 0.01% of the Urea.

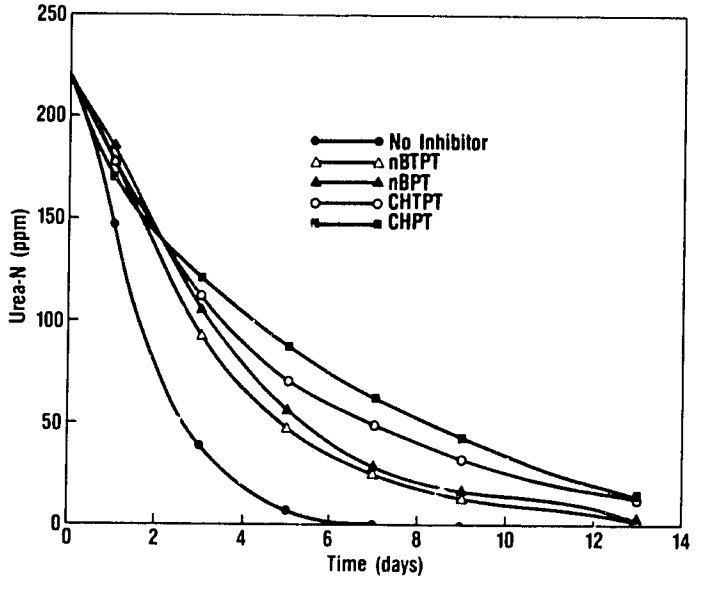


Figure 11. The Effect of Different Inhibitors (0.2%) on Urea Hydrolysis on a Flooded Windthorst Soil.

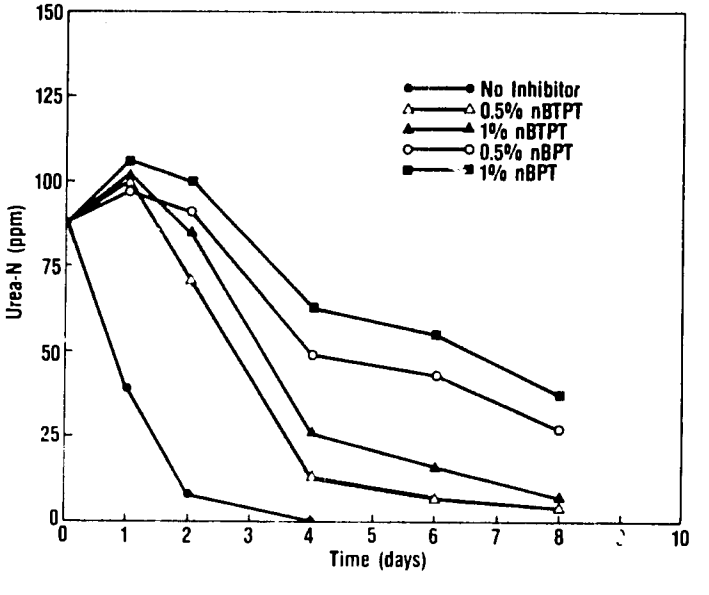


Figure 12. Comparison of the Oxygen and Sulfur Analogs as Urease Inhibitors With Fertilizers Incorporated into Flooded Guthrie Soil.

inhibitor: This work indicates that any soil mixing may greatly decrease the effectiveness of the sulfur compounds. Soil characteristics will also have significant effects on the rate of conversion of the sulfur to the oxygen form and thus the performance of the inhibitor.

Recent research has shown that under some conditions the nBTPT degrades to ineffective forms when it is mixed with urea. Research was begun to determine the best manufacturing techniques to make nBTPT-amended urea and how to make it more stable in the fertilizer.

Field Evaluation of Urease Inhibitors

Field evaluations were begun in four Asian countries and in two Latin American countries to determine the effect of using nBTPT in flooded rice culture to improve urea efficiency. To date, the field research with nBTPT has not confirmed the greenhouse results. Research on plantation crops (coffee, rubber, and oil palm) will begin in the future.

New Procedure Developed for Determination of ^{15}N in Soil

When conducting ^{15}N experiments, it is essential that the analytical procedures used to measure ^{15}N left in the soil recover all the available ^{15}N. This requires use of the Kjeldahl procedure, which involves a long slow digestion (4 hours) with sulfuric acid and potentially hazardous catalysts. IFDC researchers have developed a new procedure that uses a mixture of hydrogen peroxide and sulfuric acid to measure ^{15}N. This procedure is much more rapid (38 minutes) and is easier to use than the traditional method. Results from the new technique are equivalent to those of the Kjeldahl procedure while reducing the sample handling and eliminating the need for catalysts.

Future work will adopt the procedure for the determination of other elements in soil, including phosphorus and micronutrients such as iron, manganese, magnesium, etc. The procedure has also been modified for use with plant materials and allows an equal saving in time of analysis and required reagents.

Direct Measurement of Fertilizer Losses Through Denitrification

IFDC soil scientists have been conducting research for the past 5 years aimed at directly measuring the amount of fertilizer loss that occurs through denitrification. Denitrification is a biological process by which plant-available nitrate-nitrogen becomes unavailable or is "lost" as nitrogen gases. It has been considered by many to be a major reason for the inefficiency of nitrogen fertilizers applied to flooded rice soils and on upland soils that are saturated by rainfall. If methods can be devised to directly measure denitrification losses, an assessment can be made of how important the losses are in various cropping environments and what fertilizer modifications or management techniques might be used to decrease the losses. Another important reason to be able to measure the losses directly is that one gaseous product, nitrous oxide, is implicated as a causative agent in global warming and the destruction of the ozone layer. In this context, it is important to know the impact that nitrogen fertilizer has on the nitrous oxide accumulation in the atmosphere.

The methods to measure denitrification have used the heavy stable isotope of nitrogen (^{15}N). When ^{15}N fertilizer is placed in the soil, the amount of ^{15}N in the gaseous products can be measured, and the fertilizer losses can be calculated. Efforts to accurately account for denitrification losses with direct measurement have shown losses of only a small percentage of the fertilizer. This contrasts sharply with estimates of 10%-30% of the fertilizer derived by other groups using indirect methods of measurement on flooded soils.

One problem in measuring losses is that the gaseous products remain trapped for some time in the soil rather than moving out of the soil and into the atmosphere where they are measured. By using a cloth bag of soil buried in the larger soil mass, IFDC scientists found that about 75% of the gas produced by denitrification was entrapped in the soil.

Inclusion of this procedure has enabled a better accounting for nitrogen lost through denitrification, but a full accounting has not yet been possible in field studies. Despite the possible underestimation of denitrification losses by direct measurement techniques, the data continue to indicate that, contrary to the widely accepted belief, denitrification accounts for only a small amount of the losses of urea applied to flooded rice. IFDC researchers will continue to try to better estimate denitrification losses in flooded rice soils.

Phosphorus Research

Field Research in Indonesia

Indonesia has made great strides in agricultural production. A combination of many factors is responsible, but increased fertilizer use is a major one. However, fertilizers are highly subsidized in Indonesia, and the cost of the

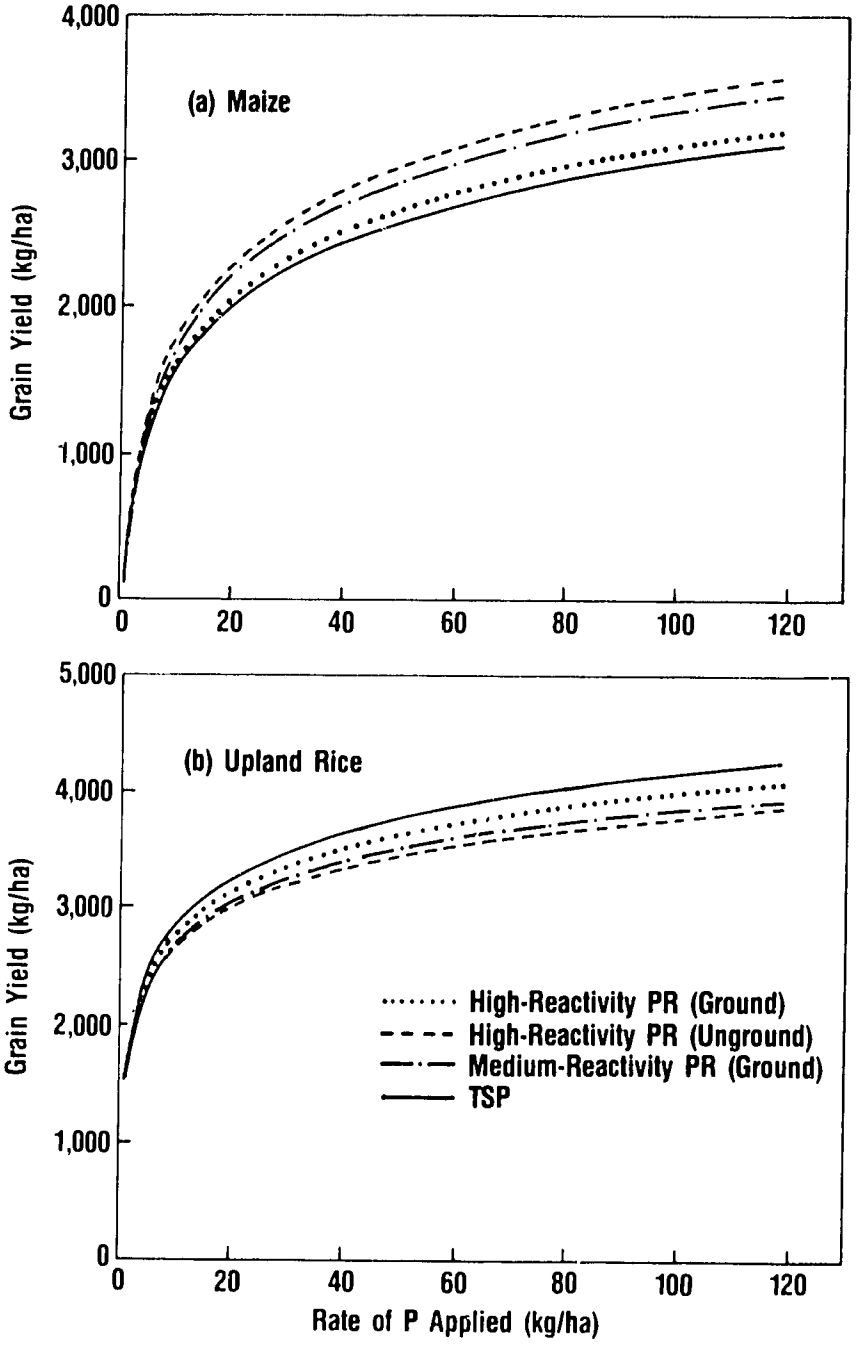


Figure 13. Effect of P Fertilizers on Crop Yields Obtained on Acid Soils at (a) Palembang and (b) Terbanggi in Indonesia.

subsidy has become a major drain on the Indonesian national budget. The subsidy on TSP is greatest among fertilizer materials because of the high cost associated with domestic TSP production. Improving the economics of phosphorus use by introducing a lower cost per unit of phosphorus yet agronomically effective source could permit a reduction in subsidy without reducing farmer income or increasing prices of crops. The introduction of reactive phosphate rock for direct application as a substitute for TSP in selected markets might offer a considerable saving at the national level for Indonesia since the major portion of their upland agricultural production is located on acid soils.

In 1988 IFDC collaborated with the Centre for Soil Research of the Agency for Agricultural Research and Development (AARD) of the Indonesian Government to conduct five researcher-managed field experiments in Sumatra, Indonesia. The objectives of this research were to: (1) determine the need for grinding reactive phosphate rock used for direct application, (2) estimate the agronomic effectiveness and hence costs and benefits of directly applied phosphate rocks of medium and high reactivity relative to TSP, and (3) formulate rates of application of directly applied phosphate rock.

In general, the results from the first season indicate that phosphate rocks of medium and high reactivity were almost as effective as TSP in improving maize and upland rice grain yields on a range of representative acid soils in southern and central Sumatra. The results also show that finer grinding did not greatly influence crop response to the high-reactivity phosphate rock (Figure 13). Similar results were also obtained from greenhouse experiments conducted at IFDC Headquarters. The field experiments will be repeated over a period of 3 years to evaluate residual effects and determine maintenance application rates after which the economic implications of these agronomic results to Indonesian agricultural production will be assessed.

Sulfur Research

Field Research in Thailand

Following the lead of other southeast Asian countries, Thailand is shifting increasingly to urea as the principal nitrogen fertilizer for rice. Deficiencies of sulfur are well-documented on the light-textured soils of Thailand's northeast plateau. Thus, a shift to urea may be expected to lead to increased occurrence of sulfur deficiency in that region. In 1987

Table 5. Recovery of Fertilizer Sulfur by Rainfed Rice at Ubon Ratchathani, Thailand (1987)

	Urea-Elemental S		Urea-Ammonium Sulfate	
	Surface Applied	Broadcast and Incorporated	Surface Applied	Broadcast and Incorporated
	(% applied)		(% applied)	
Grain	7.4	6.7	5.1	5.7
Straw	14.2	13.1	12.4	10.4
TOTAL	21.6	19.8	17.5	16.1

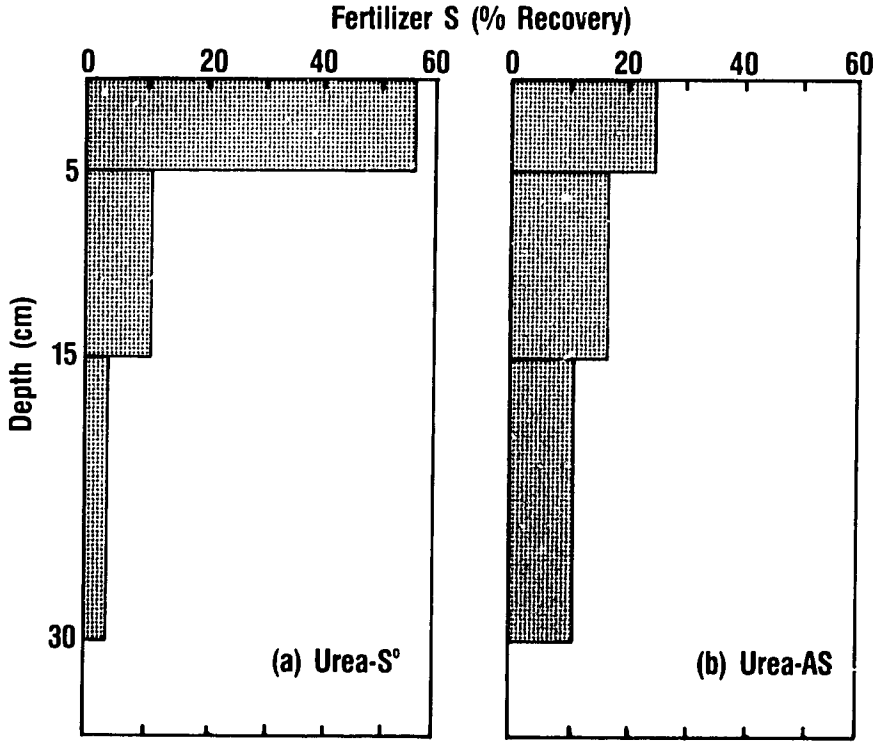


Figure 14. Residual Fertilizer Sulfur in a Rainfed Rice Soil at Harvest at Ubon Ratchathani, Thailand.

IFDC established a collaborative experiment with the Department of Agriculture at the Ubon Ratchathani Rice Research Station to compare alternative methods of supplying plant nutrient sulfur with urea fertilizer to rainfed rice in a rice-soybean cropping sequence. Since methods of applying nitrogen and sulfur fertilizers to flooded rice soils may affect the efficiencies of both nutrients, two alternatives: (1) surface application onto dry soil prior to flooding and (2) broadcasting and incorporating into flooded soil at transplanting were also compared. Two urea-based sulfur-containing fertilizers with identical nitrogen:sulfur ratios were tested: a granulated urea-elemental sulfur mixture (40-0-0-14) and a granulated urea-ammonium sulfate mixture (34-0-0-12). Both types of materials are produced commercially although at different nitrogen:sulfur ratios. Sulfur in both materials was labeled with S-35 to estimate fertilizer sulfur use efficiency and to determine the fate of residual sulfur in the soil.

Possibly due to residual sulfur from previous applications of sulfur-containing fertilizer on the station, rice did not respond significantly to sulfur fertilizers in this experiment. Fertilizer sulfur recovery in grain and straw was approximately 19% of the sulfur applied and was not significantly affected by sulfur source or application method although uptake from the elemental sulfur source tended to be greater than from the sulfate source (Table 5). This shows that oxidation of elemental sulfur to the available sulfate form was sufficiently rapid to satisfy crop requirements whether it is applied to the aerobic zone at the soil surface or incorporated into the reduced zone of flooded soil.

Approximately 85% of the residual fertilizer sulfur was recovered from the soil profile. Whereas the elemental sulfur tended to be concentrated near the surface, sulfur derived from ammonium sulfate was more uniformly distributed down to 30-cm depth (Figure 14). Unlike elemental sulfur, which must first be oxidized to the soluble sulfate form, ammonium sulfate is in a leachable form from the time of application. Nevertheless, although sulfur from both sources was detected below 30-cm depth, movement into the lower profile was minimal. Thus, substantial residual effects, particularly to elemental sulfur, may be expected on this soil. These effects are being determined in follow-up croppings with soybeans and rice in the 1988 season.

Technical Assistance

China

Under sponsorship of the United Nations Industrial Development Organization (UNIDO), an IFDC geologist visited the Lianyungang Chemical Mines Design and Research Institute, Ministry of Chemical Industry, during 1988. The geologist presented a number of seminars dealing with phosphate ore—characterization, the world fertilizer situation, and beneficiation methods.

In addition, through sponsorship by UNIDO, IFDC arranged for an NFDC chemical engineer to visit the Shanghai Research Institute of Chemical Industry. The engineer provided several lectures on NPK fertilizer production technology.

India

The Gujarat State Fertilizer Company, Ltd. (GSFC) of India sponsored a project for IFDC to supply detailed fabrication drawings and other information for that company to use in establishing a research capability in three categories: (1) laboratory-scale granulation unit, (2) laboratory for fluid fertilizer development, and (3) laboratory for physical quality evaluation. TVA supplied information to IFDC for the fluid fertilizer laboratory. GSFC is responsible for equipment fabrication and/or procurement and installation. After the equipment is installed IFDC will provide the on-site assistance of one engineer and one technician for granulation, one technician for physical quality evaluation, and one engineer for fluid fertilizer testing.

Israel

During 1988 IFDC provided technical assistance to three companies in Israel—Negev Phosphates Ltd., Dead Sea Works Ltd., and Haifa Chemicals, Ltd.

For Negev Phosphates IFDC performed laboratory beneficiation tests on two samples of Nahel Zin phosphate rock. One sample was the run-of-mine rock; the other was slimes from the Negev Phosphates beneficiation plant. The laboratory test results were encouraging enough to recommend testing in larger-scale equipment.

Granular, well-rounded potash attracts a premium price in the world market. Dead Sea Works, a major potash exporter, produces granular potash by compaction. The compacted potash is irregular in shape. As a result, the Dead Sea Works is considering wet granulation of potash. IFDC performed several tests in the bench-scale continuous pilot plant to evaluate prospective binders and operating conditions. The test results were promising and testing in large-scale equipment was recommended.

Haifa Chemicals, Ltd., the world's largest producer of potassium nitrate fertilizer, requested assistance in assessment of proposals for expansion of plant output and the associated facilities for bulk and bag handling, packaging, and dispatch, involving several grades of crystalline and prilled product. Along with a resident project team, the IFDC Distribution and Handling Specialist visited the factory in Haifa and studied the options. Agreed-upon recommendations for dealing with their rather complex options were then submitted to Haifa Chemicals management and are now being implemented.

Malaysia

The FPM Sendirian Berhad NPK granulation plant entered its sixth year of commercial operation in 1988. During this 6-year period the new FPM organization with its line of high-quality, urea-based, granular NPK-magnesium products has matured into a major and respected supplier of fertilizer to Malaysian agriculture. The high quality of the FPM products is evidenced by the Standards and Industrial Research Institute of Malaysia seal of approval for all of the primary granular products produced by FPM. During this same period the FPM organization has made significant progress in developing a cadre of skilled managers and operators, thus strengthening the fertilizer supply resource base for Malaysia and the region.

IFDC's role throughout this project has been that of technical adviser, expediter, and coordinator in most areas of process design, engineering and plant construction, operator training, and process and product optimization. During 1988 IFDC's assistance to FPM continued primarily in the areas of new formulations, the addition of secondary and micronutrients, and quality assurance.

Saudi Arabia

The United States Geological Survey (USGS) Mission in Jiddah, Saudi Arabia, has engaged IFDC through NFDC/TVA to undertake studies to evaluate development potential of the Al-Jalamid phosphate deposit of Saudi Arabia. Others involved in the project include Jacobs Engineering Group, Inc., of Lakeland, Florida; East-West Center in Honolulu, Hawaii; and the USGS offices in Reston, Virginia, and Denver, Colorado.

IFDC activities include: (1) characterization of four ore types; (2) determination of beneficiation characteristics of these ores using calcination and flotation; and (3) evaluation of beneficiated concentrates for production of wet-process phosphoric acid and diammonium phosphate. During 1988 IFDC completed the ore characterization and beneficiation studies.

The data generated by IFDC will be used by the Jacobs Engineering Group for preliminary plant design and investment/production cost analysis.

National Programs

Bangladesh

The year 1988 marked the ninth year of IFDC's continued involvement in the USAID-sponsored Fertilizer Distribution Project in Bangladesh. IFDC's technical assistance to the Government of Bangladesh and the Bangladesh Agricultural Development Corporation (BADC) began in December 1979 through a technical assistance agreement with BADC, a public-sector agricultural input marketing organization.

The goal of the project is to increase agricultural production by increasing fertilizer use through the development of a cost-effective and responsive fertilizer distribution system ensuring adequate supplies nationwide. This is to be achieved by the development of a nationwide competitive fertilizer marketing system based on private-sector involvement.

Transportation Discount Points

During 1988 innovative approaches expanded the involvement of the private sector in wholesaling activities. This was achieved by enabling wholesalers to purchase fertilizer from the main distribution centers using strategically located transportation discount points (TDPs). These TDPs are located at the focal point of the in-country transportation network and at the domestic factories. Price discounts are given to wholesalers who purchase fertilizer from these TDPs. Within a short period of time, TDPs sold a significant volume of fertilizer (about 20% of total national sales), and farmers consequently benefited from lower prices and improved availability. Total national sales were 15% higher than for the previous year.

An IFDC Headquarters' short-term consultant, in a TDP Operation Assessment, June 1988, concluded that the expansion of marketing through TDPs was one way in which BADC could minimize the difficulties that arise from the distribution and marketing of ever-increasing quantities of fertilizer while increasing the cost-effectiveness of the system.

Credit

The purpose of developing a sound credit program under this consultancy is to relax wholesalers' financial constraints and to encourage a free competitive market to provide improved availability of fertilizer to retail dealers and farmers at lower margins. IFDC's resident consultants helped to monitor and upgrade the existing BADC in-kind credit program and developed a new commercial credit program to be administered out of the USAID grant fund ($33 million) through the formal banking system designed for wholesalers and distributors. The program was approved by the Government of Bangladesh and is scheduled to begin in 1989.

Reorganization of BADC

With the success of the TDP system, IFDC recommended reorganization of BADC fertilizer activities in a manner that would accentuate BADC's agricultural development role while reducing BADC's purely stockist activities. A reorganization plan was developed by IFDC and submitted to the Government of Bangladesh and BADC for implementation. The recommended functions for BADC in the new organizational structure included:

- Market research and service function.
- Quality control.
- Credit administration and accounting.
- Planning, monitoring, and development.

- Dealer development and training.
- Sales and distribution.

The reorganization plan was approved by BADC and is awaiting early implementation.

Training

Fertilizer dealer development and training is an integral part of IFDC's consultancy services in Bangladesh. During 1988 training programs focused on large-volume wholesalers who purchase from the TDPs. A special training program was held to strengthen the business and technical knowledge of 33 large wholesalers from the Rajshahi Division. The program contributed to the overall development of wholesalers who will become responsible for nationwide marketing. IFDC also assisted BADC with 2-day training programs for retail dealers. These programs emphasized improved crop production, fertilizer knowledge, and transfer of technology to farmers. A total of 500 dealers received this formal training.

A significant effort was invested in demonstration activities to promote balanced and efficient fertilizer use. There were 135 demonstrations carried out; these included farmer field days.

Research and Development

A research and demonstration pilot project on urea deep placement was conducted in cooperation with BADC as part of the dealer development program in Bangladesh. The main objectives were to:

1. Familiarize farmers with the practice of deep placement of urea for paddy production.
2. Compare paddy yields from farmers' standard urea fertilization practices with urea deep placement.
3. Determine the potential for farmers to accept this practice.

The encouraging results of this pilot project led BADC management to expand the program using its own dealer development program resources.

An IFDC soil scientist assisted BADC in developing an expanded urea deep placement program on four BADC/seed multiplication farms and farmers' fields (demonstration plots), organized by local dealers as part of the dealer training program. IFDC also assisted BADC in developing plans for providing a supply of urea supergranules/briquettes.

A Bangladeshi farmer deep places urea supergranules in a rice paddy. An IFDC Soil Scientist, stationed in Bangladesh, is assisting BADC in conducting a urea deep placement program on demonstration farms to familiarize farmers with this management practice.

Latin America Presents Different Fertilizer Picture

Latin America Fertilizer Situation

Consumption

During the 1980s the rate of growth in total fertilizer use slowed considerably in Latin America. Compared with 12% and 10%/year growth in fertilizer use during the 1960s and the 1970s, respectively, total fertilizer use grew only at 2.7%/year during the 1980s. This slowdown in growth was experienced by both Central America and South America although it was much more for the latter because the annual growth rate for South America dropped from 12.5%/year during the 1970s to 1.9%/year in the 1980s; for Central America the drop in growth rate was from 5.4% to 4.5%. Phosphate was affected much more adversely than nitrogen and potash. There was hardly any growth in phosphate use in South America during the 1980s. Some of the factors causing this slowdown in fertilizer use are debt crises, foreign exchange shortages, low export crop prices, high fertilizer prices resulting from subsidy removal programs in countries like Venezuela and others, and the removal of subsidized credit programs in Brazil. Compared with Asia, which experienced a stable policy environment, Latin American countries experienced drastic policy changes that contributed to a volatile fertilizer market. Also, because of a low production base and high import dependence, especially of South America, many macroeconomic factors (debt crisis and foreign exchange shortages) accentuated the slow down in fertilizer use growth by reducing imports.

Total fertilizer consumption increased from 0.73 million tons in 1960 to 6.6 million tons in 1980 and 9.2 million tons in 1988. Nitrogen use increased from 0.29 million tons in 1960 to 3.99 million tons in 1988, and use of phosphate and potash from 0.30 and 0.13 million tons to 2.9 and 2.4 million tons, respectively, during the 1960-88 period.

In terms of five-year percentage changes, Latin America presents a different picture. Unlike Asia, which experienced acceleration in fertilizer use growth during the 1975-80 period, Latin America did not experience such acceleration during the 1975-80 period; its total fertilizer consumption increased at decreasing percentage rates during the 1960-85 period. Only after having experienced a very low percentage increase (9%) during the 1980-85 period, its total fertilizer use increased by a higher percentage during the 1985-88 period compared with the preceding period (1980-85). This indicates the influence of the improved macroeconomic situation resulting from restructuring of debts and additional foreign exchange available from international organizations like the World Bank and others.

Production

Compared with Asia, Latin America's share in world fertilizer production is small. In 1988, with 5.3 million tons of production, Latin America accounted for less than 4% of total world production. However, Latin America's share was higher than that of Africa.

Total fertilizer production increased from about 0.40 million tons in 1960 to 3 million tons in 1980 and 5.3 million tons in 1988. Nitrogen production increased from 0.3 million tons in 1960 to 1.5 million tons in 1980 and 3.2 million tons in 1988, and phosphate production increased from 0.10 million tons in 1960 to 1.5 million tons in 1980 and 2 million tons in 1988. Potash production increased marginally. Overall, total fertilizer production in Latin America increased at a rate of 7.17%/year during the 1980-88 period.

Excerpted from *Global Fertilizer Perspective, 1960-95: The Dynamics of Growth and Structural Change*, by Balu L. Bumb, IFDC, 1989.

Introduction

The Center's activities in Latin America during 1988 were devoted to phosphate research and technical assistance. The agronomic effectiveness of Sechura phosphate rock was evaluated for different crop species on two acid soils. In addition, IFDC scientists compared the effectiveness of PAPR and compacted phosphate rock and soluble phosphate. The purpose of this research was to determine if direct acidulation of phosphate rock with sulfuric acid to obtain a given fraction of the phosphate in water-soluble form was equivalent to a simple mixture of phosphate rock with TSP compacted into conventional-size granules.

In the technical assistance area, IFDC staff evaluated the technical and economic feasibility of building an ammonia urea complex in Bolivia. In Chile the Center provided onsite technical assistance relating to traditional processing in a fertilizer complex. At the request of a fertilizer producer in Colombia, IFDC studied ways to modify its plant to improve process efficiency, flexibility in the use of raw materials, and production capacity. In Costa Rica IFDC staff conducted a technical and financial evaluation of a government-owned fertilizer production faciility.

Research Activities

Phosphate Research

Phosphate Rock for Direct Application

Direct application of phosphate rock can be an economically attractive alternative to the use of the more expensive soluble phosphate fertilizers on acid soils in some countries that have indigenous phosphate rock deposits in Latin America. Sechura (Bayovar) phosphate rock in Peru is a highly reactive rock that is potentially suitable for direct application. In 1988 a visiting scientist from Peru, sponsored by the Organization of American States, conducted a greenhouse evaluation of the agronomic effectiveness of Sechura phosphate rock for different crop species on two acid soils (Figure 15). On the Mountview soil (pH 4.8, organic matter 1.8%), Sechura phosphate rock was less effective than TSP for wheat, maize, and flooded rice (Figure 15a,b,d), whereas it was as good as TSP for upland rice and ryegrass (Figure 15c,e). On the Hartsells soil (pH 4.8, organic matter 4.3%), Sechura phosphate rock was found to be as effective as TSP for maize and kidney beans (Figure 15f,g). Furthermore, it was found that the effectiveness of Sechura phosphate rock for flooded rice was substantially increased if applied to the acid soil 2 weeks before flooding and rice transplanting (Figure 15h). This finding is important because phosphate rock can be incorporated in the system of direct dry-seeded rice management. Fieldwork is required to test this agronomic practice of phosphate rock application.

Modified Phosphate Rock Fertilizers

Use of conventional, water-soluble phosphorus fertilizer such as TSP, SSP, and DAP has been declining in Latin America during the 1980s. The primary reasons for this are related to the high costs and foreign exchange requirements for these materials. While most Latin American countries possess indigenous phosphate rock deposits, use of these rocks is also growing at a slow rate. Direct application of finely ground rock has been extensively evaluated for use on acid, infertile soils in the region as an alternative with substantially lower capital and production costs. While this approach has proven effective under certain conditions, it is recognized that use of phosphate rock alone will not give satisfactory agronomic results with all rock, soil, and crop combinations.

Evidence has been obtained during the last several years, however, indicating that crop response to applied phosphorus is impressive even when only a portion of the phosphorus is in water-soluble form, especially in soils with high phosphorus-retention capacity such as those commonly found in Latin America. This is an important finding because it suggests indigenous phosphate rock might be used in combination with conventional fertilizers to reduce the cost of importation. Approaches that build upon the concept of combining soluble phosphorus with slowly dissolving phosphate rock include (1) partially acidulated phosphate rock (PAPR), (2) physical mixing of phosphate rock with soluble phosphate sources, (3) compaction of the physically mixed phosphate rock and soluble phosphate (with or without other nutrients), and (4) incorporation of the phosphate rock into the soil as a phosphate amendment followed by banding of soluble phosphate at reduced rates.

In 1988 IFDC scientists conducted comparisons of alternatives 1 and 3 as listed above. The tests were designed to determine if direct acidulation of phosphate rock with sulfuric

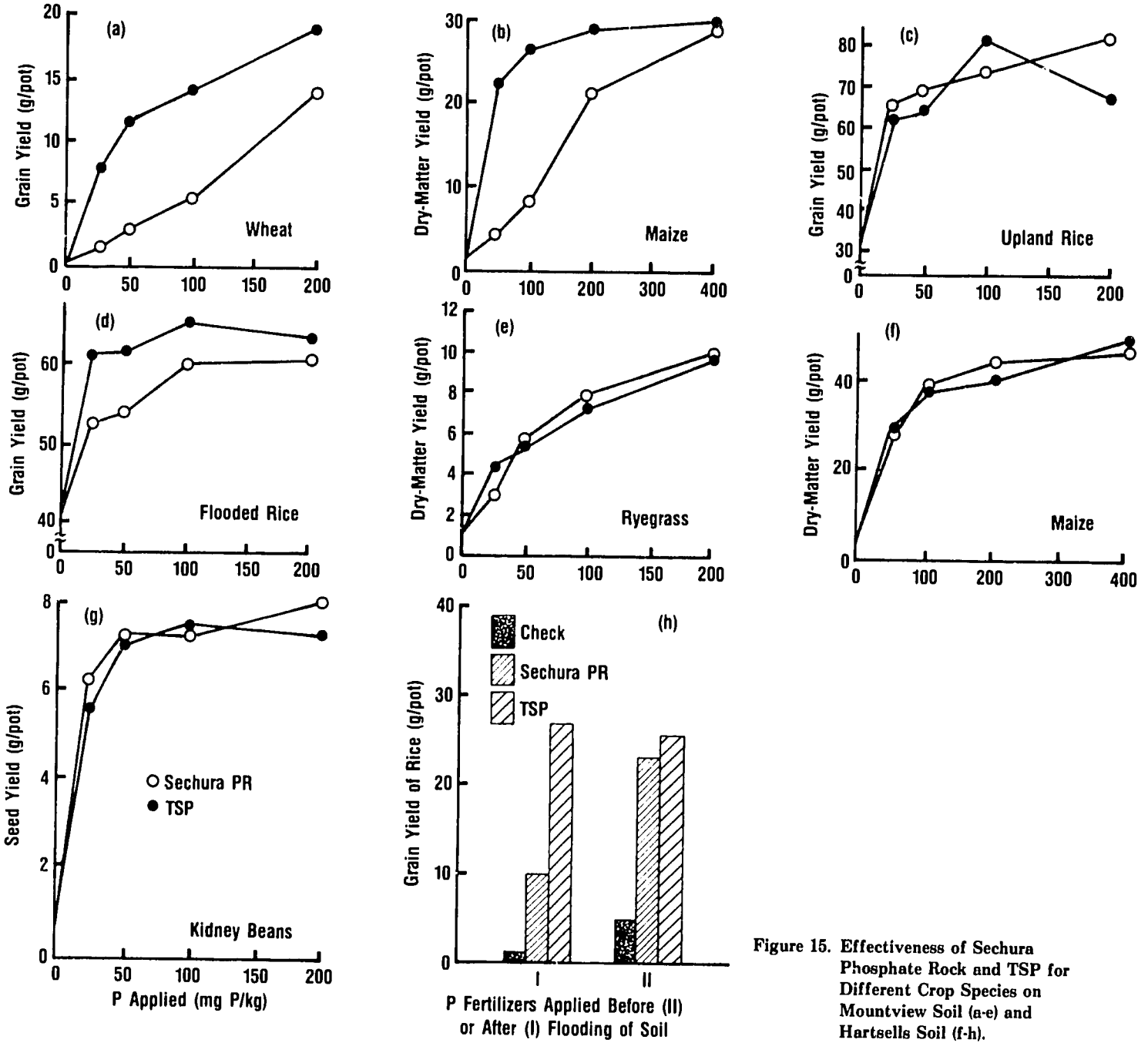


Figure 15. Effectiveness of Sechura Phosphate Rock and TSP for Different Crop Species on Mountview Soil (a-e) and Hartsells Soil (f-h).

acid to obtain a given fraction of the phosphate in water-soluble form (granulated PAPR) was equivalent to a simple mixture of phosphate rock with TSP compacted into conventional-size granules. Two Latin American phosphate rock sources, Huila from Colombia and Capinota from Bolivia, were used in one such study conducted under greenhouse conditions. To prepare the PAPR, the finely ground rock was acidulated with 50% of the sulfuric acid required to make superphosphate. The contrasting product consisted of a 50:50 mixture of the respective ground rocks and TSP subjected to compaction, crushing, and screening to an equivalent granule size (minus 6- plus 14-mesh).

The results of this trial showed that the effectiveness of Huila PAPR was the same as the compacted (Huila + TSP) mixture in increasing the dry-matter yield of maize and that both products were statistically no different from commercial TSP (Figure 16a). Similar results were obtained with the compacted mixture containing Capinota phosphate rock (i.e., it was agronomically equivalent to TSP), but the PAPR produced with this rock was *less* effective than the compacted mixture containing the same rock (Figure 16b). This finding was consistent with respect to the relative performance observed in a 1988 IFDC field trial conducted in Colombia with beans as the test crop. Data from the field trial in Figure 17b show that there was no improvement in agronomic

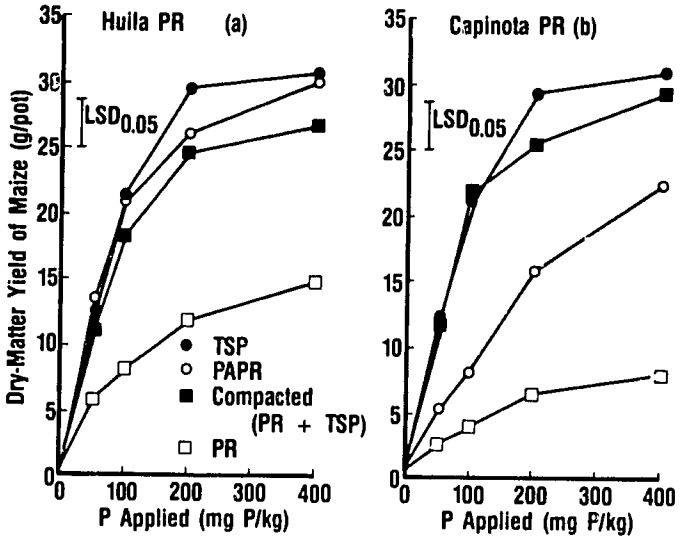


Figure 16. Dry-Matter Yield of Maize as Influenced by P Sources. (PAPR materials were prepared by partial acidulation of phosphate rocks with H_2SO_4 at 50% acidulation level and granulated to -6 + 14 mesh. Compacted material (-6 + 14 mesh) was prepared by dry compaction of mixtures of phosphate rock and TSP at P_2O_5 ratio of 50:50.)

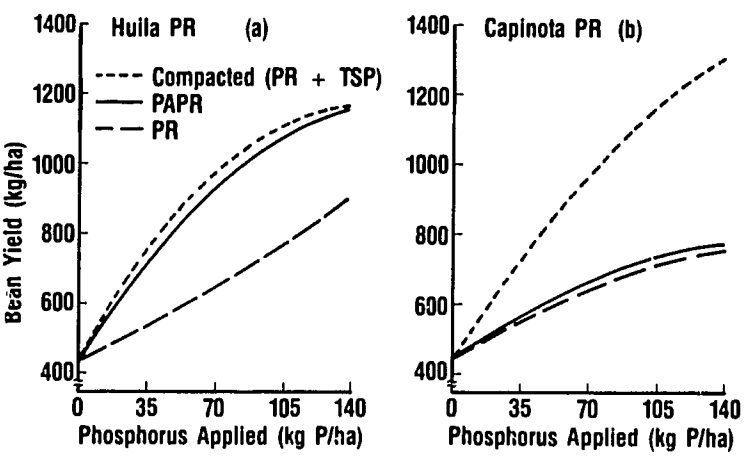


Figure 17. Effect of P Sources on Bean Yield Obtained at El Socorro-Pescador, Colombia. (PAPR materials were prepared by partial acidulation of phosphate rocks with H_2SO_4 at 50% acidulation level and granulated to -6 + 14 mesh. Compacted materials (-6 + 14 mesh) were prepared by dry compaction of mixtures of phosphate rocks and TSP at P_2O_5 ratio of 50:50.)

effectiveness as a result of partially acidulating the Capinota rock, whereas a significant improvement was obtained with both PAPR and the compacted mixture when Huila was used (Figure 17a).

Supplemental research conducted at IFDC Headquarters identified the higher iron oxide and aluminum oxide content in the Capinota phosphate rock (8.8%) than in the Huila phosphate rock (2.3%) as being responsible for the poor performance of the Capinota PAPR. Following partial acidulation of rocks containing high (>7%) concentrations of iron oxide and aluminum oxide, there is an apparent reaction of the water-soluble phosphate formed during the acidulation process with the iron oxide and aluminum oxide resulting in a reversion to water-insoluble forms. Because of this reversion, the PAPR produced from Capinota rock had a much lower water-soluble phosphate content (14.6% of the total P_2O_5) than did the Huila PAPR (51.4% of the total P_2O_5) at the same level (50%) of partial acidulation with sulfuric acid. In the absence of sulfuric acid, the iron oxide and aluminum oxide in the Capinota rock did not react with the water-soluble phosphate, thus the compacted mixture of Capinota rock + TSP had a higher water-soluble phosphorus content (50% of the total P_2O_5) and showed high agronomic performance as expected.

The research described above also indicated the care that must be taken in trying to predict the agronomic performance of nonconventional phosphate fertilizers with conventional laboratory methods. Normally, the sum of the water-soluble phosphorus + citrate-soluble phosphorus is considered completely "plant-available." In the products described above, however, it should be pointed out that the Capinota PAPR performed poorly despite having a relatively high citrate-soluble phosphorus content (31.8% of the total P_2O_5). The fact that this citrate-soluble fraction was apparently not plant available is a characteristic of iron phosphate and aluminum phosphate reversion products that typically are soluble in neutral citrate solution but are not plant available.

Results obtained in 1988, therefore, continued to support findings of previous years that products or practices that include a portion of the phosphorus applied in water-soluble form allow the crop to effectively use unacidulated phosphate rock. The findings also make it clear that it is the ability of a product to provide the water-soluble phosphorus that will determine the agronomic performance of that product, rather than the process itself. For

instance, PAPR may not be an effective process if the rocks contain high concentrations of iron oxide and aluminum oxide, but the desired results may be obtainable through a mixture of the same rock with TSP or other soluble phosphate fertilizers.

Also, during 1988 several additional field trials were established in collaboration with the National Soils Program of Instituto Colombiano Agropecuario (ICA) in Colombia. The objective of the trials was to evaluate the agronomic effectiveness of PAPR products made with local phosphate rock deposits from Huila, Pesca, and Media Luna in different regions with various crops (sugarcane, beans, maize, and potato). In general, the results show that PAPRs were good phosphate sources for crop yields, especially for potato crops that did not respond to unacidulated phosphate rocks because of their low reactivity.

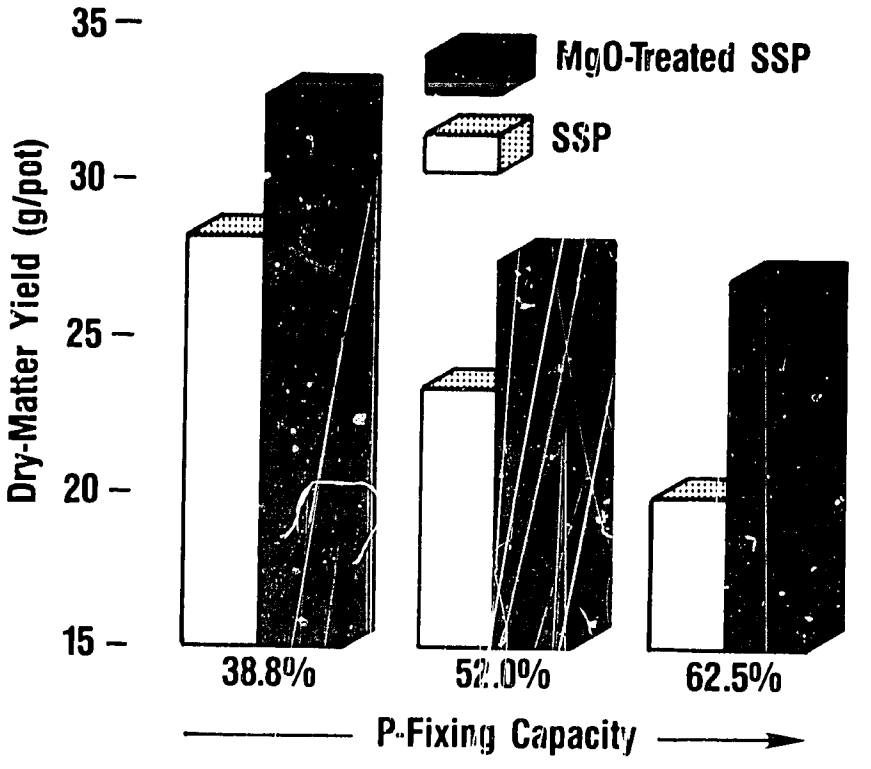


Figure 18. Dry-Matter Yield of Maize Obtained With SSP and MgO-Treated SSP on Three Soils With High Phosphorus-Fixing Capacity.

Modified Single Superphosphate Fertilizer

In tropical regions in Latin America, there are vast areas of Oxisols, Ultisols, and Inceptisols (Andosols) that are characterized by the presence of high levels of iron and aluminum oxides. These soils generally have good physical properties and are well suited for agriculture but show a high phosphate-fixing capacity.

For soils with a high phosphate-fixing capacity, nonconventional phosphate fertilizers with a retarded phosphate release may be more effective under humid conditions than water-soluble phosphate forms such as TSP and SSP. One such phosphate fertilizer can be made by adding magnesium oxide to SSP that converts part of water-soluble phosphate (monocalcium phosphate) to water-insoluble but citrate-soluble phosphate (magnesium phosphate). In 1988 IFDC's scientists conducted two greenhouse experiments to evaluate the agronomic effectiveness of magnesium oxide plus SSP as compared with SSP using maize and soybean as test crops grown on three acid soils with high phosphate-fixing capacity. The results show that magnesium oxide-treated SSP was as effective as or even more effective than SSP in phosphate availability to crops. The relative effectiveness of magnesium oxide-treated SSP with respect to SSP also tended to increase with increasing phosphate-fixing capacity (Figure 18). The economic cost of this type of product, however, still needs to be evaluated.

Technical Assistance

Bolivia

An IFDC staff member, working in collaboration with a private international marketing consultant retained by IFDC, assisted Bolivia's Ministry of Energy and Hydrocarbons and Yacimientos Petroliferos Fiscales Bolivianos, the State oil company, in evaluating the technical and economic feasibility of constructing an ammonia/urea complex at Puerto Suarez, Bolivia. The urea output of the plant would be sold mainly to Brazil as part of an energy/petrochemical supply agreement between these countries. The IFDC consultants reviewed and commented on ammonia/urea plant feasibility studies that had been made and provided information on the urea fertilizer supply/demand situation and outlook in the international and Brazilian markets as well as in other South American countries, which could be served by the proposed Bolivian plant. The need for and nature of additional studies were indicated. The consultants also provided information and assistance to the Bolivian parties in preparing for urea sales contract negotiations with their Brazilian counterparts. The private consultant traveled to Rio de Janeiro to assist in these discussions.

Chile

An IFDC geologist visited Chile during 1988 to advise Sociedad Quimica y Minera de Chile (SOQUIMICH) on various aspects of their operation to mine, process, and market soluble salts as fertilizer. The geologist made some recommendations concerning preparation of area-detailed geologic mapping to be incorporated into a comprehensive mine development plan. New data on overburden and characteristics of the potential mining areas would be used to estimate the quality of material mined and fed to the processing plant. The mineralogy of the salts such as water-insoluble, sparingly soluble, and water-soluble types should be determined. It appeared that the best potential for improvement was in developing a scheme to provide ores of specified chemical and physical properties to the extraction plants. A stable feed composition will allow downstream operations to optimize their treatment conditions and increase the efficiency and selectivity of product recovery.

A chemical engineer visited SOQUIMICH installations for 1 week in late 1988 to provide onsite technical assistance relating to their traditional fertilizer processing. During this trip, the different mining and production facilities were visited and inspected to determine ways in which procedures and equipment used in producing other types of fertilizers could be applied to the case of SOQUIMICH. At the plant site, various recommendations were given that will tend to increase the automation of the production function and help minimize losses of various materials. More detailed recommendations that will also enable a more positive control of the particle size of various products are being prepared.

This Colombian field worker harvests a rice experiment with compacted phosphate rock and PAPR in the Cauca Valley of Colombia. The IFDC/CIAT work on developing ways to use indigenous phosphate rock to produce fertilizer represents more than a decade of collaborative research.

Colombia

Abonos Colombianos, S.A. (ABOCOL), a private company with fertilizer production facilities at Cartagena, Colombia, is a major producer of nitric-acid based compound fertilizers since 1963. ABOCOL is interested in modifying its plant to improve process efficiency, obtain flexibility in the use of raw materials, and increase production capacity while, at the same time, reducing ambient pollution, corrosion, and maintenance costs. ABOCOL contracted with IFDC to determine modifications that would lead to the proposed benefits while holding the modifications to the granulation and material handling section of the plant to a minimum.

In performing this project, the following steps were carried out by IFDC:

1. The chemistry of the process was studied through theoretical calculations and actual laboratory simulations; the different modes of operation requested by ABOCOL were considered. From these studies, a modified flow sheet for the reaction section was devised. The modified flow sheet minimized the introduction of water to the process. This made possible the addition of a new gas handling and scrubbing system to more effectively treat the off gases of the plant without increasing liquid wastes.
2. The IFDC pilot plant was configured to simulate the modified flow sheet of the ABOCOL reaction section, and tests were undertaken to determine the required operating parameters, check the chemistry involved, and verify the operability of the modified plant. Six of the most important fertilizer grades of interest to ABOCOL were tested. The tests covered different formulations using different raw materials to guarantee the needed operating flexibility. These tests were carried out at capacities equivalent to one-fourth to one-half mtph of end product.
3. Complete heat and material balances were calculated for the main products to be made.
4. A process engineering package for the modified process and pollution control systems was prepared (including process flow diagrams, piping and instrumentation diagrams, and process and instrumentation data sheets) from which an engineering company can perform the detailed engineering required for the modification.

The major advantages of the proposed modifications to the plant will be:

1. Simplification of operation.
2. Enhancement of processing efficiency.
3. Reduction of corrosion problems.
4. Reduction of maintenance requirements.
5. Reduction of electric power consumption in the reaction section.
6. Increase of production capacity.

Costa Rica

At the request of Fiduciaria de Inversiones Transitorias, S.A. (FINTRA), an independent agency for privatization of government-owned companies in Costa Rica, IFDC conducted a preliminary technical and financial evaluation of Fertilizantes de Centro America's (FERTICA's) operations in Puntarenas, Costa Rica. FERTICA is a government-owned producer of ammonium nitrate, nitrophosphate-based NPKs, and bulk-blended NPKs. As a result of this preliminary evaluation, IFDC developed the scope of work for a more detailed study geared toward defining the actions required to transform FERTICA into an operation sufficiently profitable to attract future investments by the private sector.

Human Development Component Gains Momentum

In the developing countries, the personnel needed to meet the wide range of expertise in fertilizer-sector development will continue to be in short supply for the foreseeable future. In fact, UNIDO predicts that an additional 6,400 technical and 2,200 nontechnical personnel will require training each year between now and 2000 in order to meet the workforce requirements for fertilizer production alone. When those people needed for fertilizer marketing and use are added to these numbers, the requirements are doubled. Thus, sharply focused training programs are necessary if the developing-world fertilizer sectors are to function successfully by the turn of the next century.

Recognizing the need for trained personnel in the fertilizer sectors of developing countries, IFDC has increased its commitment to developing a cadre of talented professionals capable of operating all components of the fertilizer sector. In this way, the constraints associated with technology transfer should be relaxed or even removed completely.

The basic objective of IFDC's human development component is to improve the operation and cost-effectiveness of fertilizer supply and marketing systems and to improve the efficiency of fertilizer use through upgrading research and extension capabilities. Junior middle-level managers and professionals who have career development potential are the primary targets of this training.

The Center offers both general and specialized training. The former involves group training programs and workshops. Those of global outreach may be conducted at Headquarters or overseas. Those programs having a regional perspective are usually undertaken in locations in Africa, Asia, or Latin America. The general training programs are usually from 2 to 6 weeks in duration.

The specialized offerings are tailored to meet the unique requirements of both individuals and groups. The individual training usually takes place at Headquarters or at the Center's West Africa base but may also include marketing and industrial organizations in the United States or Europe. These programs are based on requests from individual countries.

Andy Cayanga (lower left), fertilizer wholesaler in Cabanatuan City, Philippines, provides IFDC training participants a look into the real world of fertilizer marketing by giving a detailed description of his fertilizer marketing practices. IFDC's training activities are enhanced greatly by the cooperative efforts of many individuals and their organizations throughout the world.

Partners in Developing Human Resources

Recognizing the need for wide-based support of its training component, IFDC continues to enlist the cosponsorship and cooperation of other international organizations, national governments and institutions, fertilizer industry associations, and the private sector. These linkages provide a very important dimension to all the programs but particularly for those programs conducted overseas. Other organizations assist IFDC with the training programs by providing physical facilities and resource persons. In addition, these copartners in training arrange for field trips. Such linkages assist the cosponsoring organizations in developing the capabilities of their own personnel. Thus far, IFDC has cooperated with 22 international and national organizations.

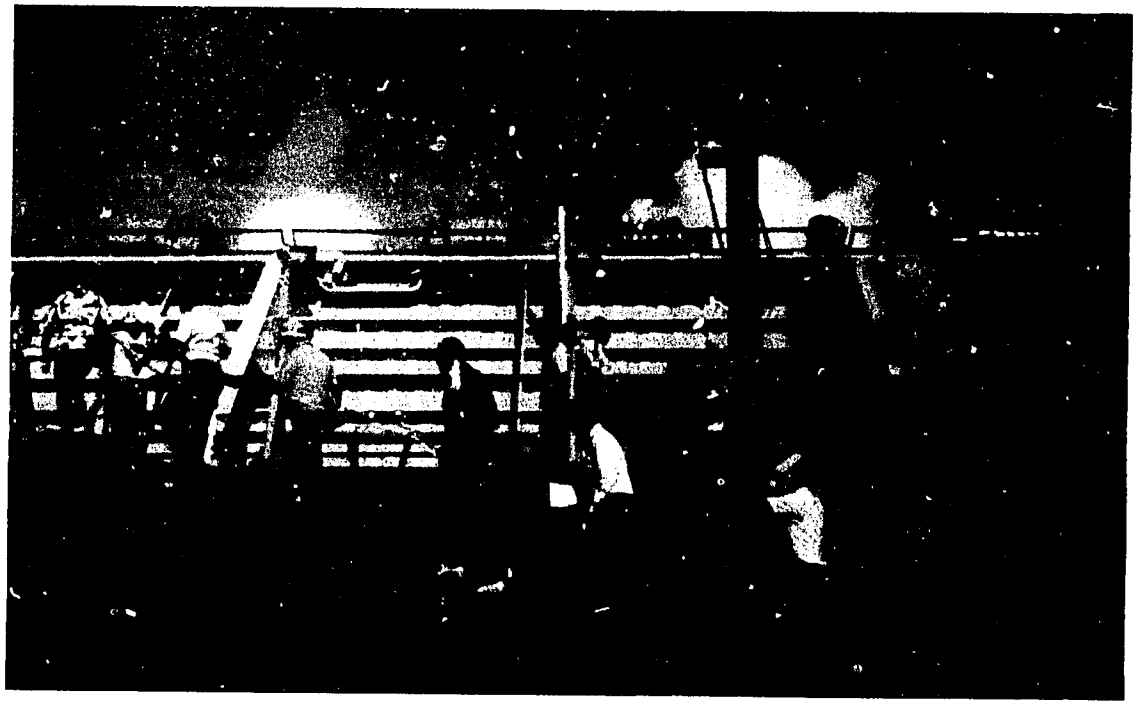
Private-sector companies are also very supportive and make key inputs into most training programs without cost. In particular, support has been received from North American, European, and East Asian companies.

1988 Training Activities

In 1988 IFDC organized 25 training programs in which 299 marketing managers, researchers, scientists, distribution managers, engineers, economists, and statisticians took part. They represented over 160 organizations from 63 countries. The countries represented for the first time in IFDC training programs were: Algeria, Bahrain, Cyprus, El Salvador, Finland, France, Guatemala, Guinea, Iran, Lebanon, Qatar, Rumania, Sultanate of Oman, Yemen Arab Republic and Yemen Democratic Republic.

The 25 training programs included 11 general group, 12 special training programs, and two workshops. Six general group training programs were held in the United States and five overseas. One workshop was held in the United States and the other overseas. First-time offerings in the category of general group training programs during 1988 were Investment Analysis and Decisionmaking, Research in Effective Fertilizer Use (Middle East), Advances in Fertilizer and Irrigation Technology, and Fertilizer Sector Development for Graduate Students. Fourteen specialized programs held in the United States covered a variety of subject-matter areas.

IFDC received the cooperation and assistance of about 150 resource persons from 75 organizations on the faculty of its programs. The outside faculty supplemented the efforts of IFDC specialists who formed the core faculty. These resource persons represented international organizations: International Center for Agricultural Research in the Dry Areas (ICARDA); Centro Internacional de Agricultura



Participants in the Fertilizer Distribution and Handling Training Program visit port facilities in Indonesia. Field trips provide a practical insight for participants in IFDC's training programs.

Tropical (CIAT); World Bank; FADINAP; fertilizer companies in Europe and the United States; industry associations; U.S. universities; U.S. federal government organizations; and private-, public-, and cooperative-sector fertilizer companies in developing countries—India, Malaysia, Guatemala, Colombia, Indonesia, and Thailand. Developing-country expertise comprised 20% of the total faculty resource in 1988.

Eighteen women participants representing nine countries attended the various programs in 1988.

General Training Programs

During 1988 IFDC conducted 11 general training programs as outlined in Table 6. Programs are grouped under the following subject-matter categories: Fertilizer Production Technology, Fertilizer Marketing, Fertilizer Use Research, and Fertilizer Sector. Included in these programs were four new offerings.

Investment Analysis and Decisionmaking for Fertilizer Sector Projects was conducted for the first time in 1988. This program attracted middle- and senior-level economists, financial managers, planners, investment advisers, and operations officers and managers in public- and private-sector fertilizer and agricultural sector-related organizations.

The program had several objectives. It sought to increase the participants' knowledge of the role of investment analysis in selecting and implementing appropriate fertilizer sector projects. It also proposed to enhance understanding of the relationship between the fertilizer supply and use components of the fertilizer sector in project investment analysis. The faculty strived to develop the participants' skills in identifying project alternatives, defining project scope, and preparing cost estimates. The criteria and techniques used in evaluating the technical, economic, and financial feasibility of fertilizer sector projects were examined. Analytical skills were enhanced through participant involvement in practical cost estimating and investment analysis exercises and case studies.

The program content focused on short- and long-term fertilizer demand forecasts; estimation of capacity requirements of selected fertilizer supply and distribution systems; determining impact of fluctuations in demand and capacity utilization on project feasibility; fundamental concepts, indices, and techniques used for cost estimation and financial/economic analyses; and project evaluation including impact on foreign exchange requirements, shadow prices, and subsidies.

Offered for the first time in the Middle East was a program on research on effective fertilizer use. Practicing agronomists and soil scientists responsible for field experimentation participated in this activity. The objectives of this offering were to identify and describe the components of a sound national fertilizer program, to review recent advances in soil and crop science and enhance understanding of factors affecting crop response to fertilizer, and to highlight problems of soil fertility maintenance under different cropping systems and socioeconomic conditions of the farmer. In addition, the faculty sought to enhance the participants'

Table 6. 1988 General Training Programs

I. **IFDC Headquarters Programs**
   A. **Fertilizer Production**
      1. Investment Analysis and Decisionmaking—Fertilizer Sector Projects
      2. Technical Management of Fertilizer Production Units
   B. **Fertilizer Marketing**
      1. Fertilizer Marketing Management
   C. **Fertilizer Use Efficiency**
      1. Soil Testing and Fertilizer Management
   D. **Fertilizer Sector**
      1. Advances in Fertilizer and Irrigation Technology in the United States
      2. Fertilizer Sector Development for Graduate Students

II. **Regional Programs**
   A. **Fertilizer Marketing**
      1. Fertilizer Distribution and Handling[a] (India-Singapore-Indonesia)
      2. Mercadeo de Fertilizantes[b] (Colombia)
      3. Fertilizer Marketing[c] (Thailand)
   B. **Fertilizer Use Efficiency**
      1. Research on Effective Fertilizer Use[d] (Syria)
      2. Analisis Estadistico y Economico sobre Uso de Fertilizantes[b] (Colombia)

a. Cosponsored by FAI and APPI.
b. Cosponsored by CIAT.
c. Cosponsored by Thailand Ministry of Agriculture and Cooperatives.
d. Cosponsored by ICARDA

ability to test and evaluate conventional and new fertilizers and application methods using the latest techniques in field research and to ensure that necessary techniques for processing, analyzing, and interpreting data generated from trials were fully understood and practiced.

Two programs focusing on the broader aspects of fertilizer sector development and operation were offered for the first time in 1988. One was devoted to Advances in Fertilizer and Irrigation Technology in the United States. This program explored the most advanced fertilizer and irrigation technologies employed in the United States. The participants visited, observed, and discussed the application of the latest fertilizer production, marketing, and irrigation-related fertilizer use technologies with irrigation equipment manufacturers and marketers, fertilizer producers, dealers, researchers, and farmers. In addition, they had the opportunity of discussing and evaluating the relevance of observed technologies to their home country situations.

The irrigation technology program captured the attention of senior-level managers of fertilizer and other farm input organizations and senior government officials with responsibilities for planning, developing, and implementing fertilizer use-related agricultural development policies and programs.

Another new offering focused on Fertilizer Sector Development for Graduate Students. This program was offered in collaboration with the Department of Agronomy of Purdue University. The program was open to graduate students and other individuals possessing Bachelor of Science or equivalent degrees in agronomy, business, chemistry, economics, engineering, marketing, management, or soil science. With the approval of their institutions, qualifying students were eligible for a credit of 2 semester hours toward their graduate degrees.

The objectives of the program included providing knowledge and problem-solving experience on issues related to fertilizers and food production, crop and soil management, economics of fertilizer use, fertilizer marketing and distribution arrangements, fertilizer production technologies, and macroeconomic and sectorial policies affecting fertilizer sectors in developing countries. In addition, the participants identified major problems that developing countries face in managing their fertilizer sectors.

Specialized Training Programs

In 1988 IFDC conducted 12 specialized training programs involving 18 individuals from 8 countries. Specialized training programs dealt with various facets of fertilizer production, marketing and use research as shown in Table 7, which also indicates participants' home countries and duration of individual programs. All programs were conducted at IFDC Headquarters.

Table 7. 1988 IFDC Specialized Training Programs

Program	Participants		Program
	Country	Number	Length (days)
Fertilizer Production Technology			
Phosphate Rock/PAPR Production and Use	U.S.A.	1	21
Phosphate Rock Beneficiation	China, P.R.	1	360
Phosphate Mineralogy	China, P.R.	1	360
Urea Granulation and Sulfur-Coated Urea	China, P.R.	1	180
Phosphate Fertilizer Production	China, P.R.	1	330
Fertilizer Marketing			
Fertilizer Distribution and Handling	Kenya	3	12
Fertilizer Distribution and Handling	Nigeria	5	12
Fertilizer Use Research			
Fertilizer Use Efficiency Techniques	China, P.R.	1	365
Rice Modelling	Philippines	1	180
Fertilizer Use Efficiency Techniques	India	1	90
Micronutrients	Pakistan	1	4
Soil Fertility and Fertilizer Use	Madagascar	1	14

Workshops

NPK Fertilizer Production Alternatives

Because there is increasing interest in the use of multinutrient fertilizers in the developing countries, an in-depth review of the current status of multinutrient (NPK) fertilizer production technology and supply was considered essential and urgent. Therefore, an international workshop on NPK fertilizer production alternatives was organized by IFDC and cosponsored by FAI and FADINAP. The objective of the workshop, held in India, was to examine the alternatives for producing NPK fertilizer. The examination included the presentation of 24 technical papers, followed by an in-depth critique by the Workshop delegates.

A copy of the Workshop proceedings (IFDC-SP-9) is available from IFDC. This publication represents a very comprehensive coverage of the current status of worldwide fertilizer production technology; therefore, it provides a useful reference on a complex range of technical topics including the following:

1. Role of NPK Fertilizers in Optimizing Agricultural Production.
2. NPKs in Perspective—Fertilizer Products and Farmer Needs.
3. The Role of Agglomeration in the Fertilizer Industry.
4. Nitrophosphate Technology and Comparative Economics.
5. Compaction/Granulation of Fertilizers.
6. Comparative Advantages and Disadvantages of Blended and Granulated NPK Fertilizers.
7. Economic Comparisons of Selected NPK Fertilizer Production Alternatives.
8. Practical Experiences in the Granulation of Urea-Based NPKs.
9. NPK Compound Fertilizer Production Technology.
10. Optimizing the Formulation of NPK Fertilizer Grades.
11. DAP/NPK Performance Improvement by Retrofitting.
12. Design of Granulators, Dryers, and Coolers for Use in NPK Plants.
13. Impact on Fertilizer Formulations and Ambient Conditions on NPK Plant Design and Capacity.

Fertilizer Sector Development in Mediterranean, Middle East, and North Africa

The second workshop was captioned, "Workshop on Fertilizer Sector Development and Agricultural Production in Selected Countries of the Mediterranean, Middle East, and North Africa." This Workshop was organized at the request of and funded directly by United Nations Development Programme (UNDP). A Workshop Summary report (IFDC-SP-8) was prepared and is available from IFDC.

Workshop objectives included identification and the development of key issues affecting the organization and operation of the supply, marketing, and distribution, and use-related components of the fertilizer sector. Policy options and strategy guidelines were formulated for strengthening fertilizer research, extension, and supply and marketing systems and programs aimed at speeding information transfer and hastening the adoption of more efficient fertilizer use technologies by small and large farmers alike. Delegates were afforded the opportunity of observing and discussing practical aspects of fertilizer sector operations in the United States through visits and discussions with fertilizer producers, marketers, researchers, organizations, and farmers.

This Workshop was open to senior-level public- and private-sector planners, administrators, and managers having decision-making responsibilities and engaged in various facets of national fertilizer sector development and operation of its fertilizer production, marketing, and distribution; use research; and extension components.

Participants' Evaluation

Evaluation of training programs is an ongoing, integral part of IFDC's training effort as it strives to improve current training programs and to develop new training opportunities, which are more attuned to the needs of individuals in the developing world. The comments of participants as to the relevance and usefulness of the training programs in which they have taken part are particularly important considerations in the improvement and development of IFDC's training programs. Participants' views are obtained through informal discussions with participants and through their completion of formal program-evaluation questionnaires. Although the structure of the program-evaluation form may vary between programs because of differences in subject matter and manner of conduct, the questions posed generally seek to determine the reactions of participants in the following areas: (1) technical aspects, (2) administrative aspects, (3) methodology, and (4) field trips—organization and relevance, (5) design of the programs' structure, and (6) physical factors related to location of the programs. Other comments are also requested.

Evaluation by the participants in IFDC's 1988 general training programs indicate mean ratings of these programs ranging from a low of 2.93 (between "fair" and "good") for the Research on Effective Use of Fertilizer program held in Aleppo, Syria, to a high of 4.82 (between "very good" and "excellent") for the Analisis Estadistico y Economico sobre Uso de Fertilizantes training program held in Cali, Colombia. Except as noted above, all group training programs received overall ratings above 4.0.

As noted earlier, participant inputs are important in planning the types of training programs that may be required, subject-matter emphasis, instructional methodology, program administration, and location. In 1988 three new training programs and two new workshops were developed and carried out. Changes were made in previously presented programs in part in response to the comments of participants, IFDC staff, and guest faculty. Continuing the practice of recent years, greater use was made of guest faculty from the developing and the developed world. Training programs featured increased emphasis on the use of microcomputers, reflecting their expanding application in the various facets of fertilizer sector development and operation.

Participants in IFDC's Training Program on Fertilizer Marketing listen to a presentation by the program faculty. This program, conducted in Spanish at CIAT, is one of IFDC's growing number of training offerings, providing practical information that can be applied in the participants' countries to create more effective fertilizer sectors.

Agrominerals Data Bases

During 1988 work continued on the collection and entry of information into databases on fertilizer raw materials and phosphate rock analyses. By the end of 1988 IFDC had accumulated a bibliographic list of over 4,000 references relating to phosphate rock, sulfur, potash, energy minerals, agricultural lime, and other agrominerals. The phosphate rock characterization database contains chemical and mineralogical data for 1,100 samples from 175 deposits from over 75 countries.

Fertilizer Use Efficiency Data Base Management

Specific approaches in fertilizer use evaluation and efficiency testing have been the evaluation of field experimental techniques and the establishment and maintenance of a data base system from experimental data to promote, at national and regional levels, the efficient use and management of new fertilizer sources and fertilizer management practices. This system has been valuable in providing updated information for on-farm evaluation, fertilizer policy studies, and production alternatives and in developing fertilizer research activities to improve and sustain land productivity and agricultural production. General characteristics of the areas and information gathered are depicted in Table 8.

Data from greenhouse studies, agronomic trials, and surveys have been stored, retrieved, and analyzed by using computerized systems. This information is being evaluated through collaboration with researchers and representatives of collaborating government institutions in Africa, Asia, and Latin America.

Assistance has been provided in the establishment of systems to analyze fertilizer data at regional and national levels in Brazil, Colombia, Mali, Senegal, Togo, Uganda, and Venezuela. With this assistance, guidelines have been provided for recording and analyzing experimental or behavioral data related to fertilizer use and crop response.

Methods and procedures for statistical and economic evaluation of fertilizer data at experimental sites and on farmers' fields have been revised and updated. This analytical work is supporting research activities on fertilizer product evaluation, residual effects of fertilizer products, fertilizer evaluation in crop rotation systems, fertilizer recommendation systems, and methods of soil analysis calibration.

This IFDC team builds computer simulation models to help solve the crop production puzzle. These models can help developing-country policymakers and farmers minimize their risks and increase crop yields. From left, the team members are: (standing) Dr. C. A. Baanante, Economist; Dr. Upendra Singh, Systems Modeller/Soil Scientist; (seated) Dr. Doug Godwin, Agronomist/Systems Modeller; and Carla Humphries, Computer Operator/Programmer.

Crop Growth Simulation Modelling

Crop Evaluation Through Resource and Environment Synthesis (CERES) Sorghum and Millet Models

During the year IFDC specialists continued extensive development work on the soil fertility and fertilizer components of the CERES sorghum and millet models. These models were developed as the result of a collaborative effort between ICRISAT, International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), and Michigan State University. The models can reliably simulate a wide range of parameters affecting crop growth including the day-to-day nitrogen and water balance in various sorghum and millet cropping systems. The models also predict leaf area development, crop ontogeny, and crop growth. The models have the capacity to describe the growth and yield response to additions of nitrogen fertilizer in diverse cropping environments. They can be used to identify probable causes of inefficiency of fertilizer nitrogen utilization and to estimate the magnitude of nitrogen losses from the system. As such the models can be used as powerful tools for such applications as:

1. Assistance with farm planning.
2. Agroclimatic zoning.
3. Risk analysis for strategic planning.
4. Within-year management decisions.
5. Large area yield forecasting.

Table 8. Summary of Data Types in IFDC Fertilizer Use and Efficiency Data Management System

Fertilizer Evaluation System						
Country Experimentation	Predominant Ecosystems	Predominant Soils	Fertilizers	Cropping Systems	Management Practices	Data Types
Africa:	Humid tropics	Ultisols	Nitrogen:	Rice	Cultivar	Soil classification schemes
Nigeria	Semiarid tropics	Inceptisols	Urea	Maize	Planting date	Soil chemical and physical analyses
Senegal	Sahelian belt	Alfisols	Urea supergranule	Millet	Plant density	Tissue analyses
Togo	Equatorial lowlands	Oxisols	Calcium ammonium nitrate	Sorghum	Fertilizer application methods	Weather (site, daily, monthly)
Liberia	Subhumid tropics	Low organic matter	Ammonium sulfate	Groundnuts	Crop protection	Crop and fertilizer management
Cameroon	Tropical savanna	Low pH	Phosphorus:	Millet/cowpeas	Harvesting method	Crop production and fertilizer prices
Sierra Leone	Andean	High P fixation	Triple superphosphate	Beans		Farmer use of fertilizer
Gambia	Andean lowlands		Simple superphosphate	Potatoes		
Ghana	Tropical seasonal		Phosphate rock	Cassava		
Niger	Tropical forest		PAPR	Maize-cotton		
Benin			Sulfur	Maize-groundnut		
Burkina Faso			Complex products	Pastures		
Guinée			Coated products			
Kenya						
Zimbabwe						
Mali						
Latin America:						
Colombia						
Brazil						
Bolivia						
Ecuador						
Peru						
Venezuela						
Mexico						
Costa Rica						
Asia:						
Philippines						
Indonesia						
India						
Bangladesh						

6. Identification of agronomic situations in which nitrogen response would be expected or contra-indicated.

Validation

Data from 5 years of field experiments generated by IFDC's UNDP-funded project at ICRISAT were used to validate the sorghum model. The data were from a wide spectrum of climatic, soil, and nitrogen fertilizer management conditions. As a further test, data from independent experiments in Australia were assembled and comparisons made with simulations. The predicted and observed data for grain yield and nitrogen uptake confirmed the effectiveness of the model.

Application of the Models in Fertilizer Strategy Evaluation

A workshop jointly organized by IFDC, ICRISAT, and IBSNAT was held at ICRISAT to familiarize scientists from Indian agricultural research institutes with the models' use. During the workshop economic risks associated with N fertilizer use in some semiarid regions of India were studied. Several fertilizer strategies were evaluated at each site by simulating crop growth and response to fertilizer. In this study crops were simulated in each of 25 consecutive growing seasons using daily weather data. The simulation study demonstrated advantages of splitting fertilizer applications in wet locations. In intermediate rainfall locations the simulation indicated how other N losses occurred and how other economic advantages of splitting could be attained. Simulation studies such as these can rapidly provide insights into fertilizer behavior and the feasibility of adopting various strategies.

CERES Rice Model

New procedures for simulating the dynamics of nitrogen in floodwater in rice cropping systems were developed. These were incorporated into the new CERES RICE V2.00 model being jointly developed by IFDC and IBSNAT. The new model incorporates a water balance component that simulates the daily evaporation, runoff, percolation, and crop water uptake in bunded and nonbunded systems. The model can simulate water-nitrogen balance under fully irrigated conditions, rainfed conditions where the paddy will be intermittently flooded, and fully upland conditions where the soil is never flooded. The model simulates the growth of leaves, stems, roots, and panicles of a single plant growing within a community of plants. Light interception, photosynthesis, and partitioning of assimilates between these various organs are also simulated. The model also simulates the distribution of root growth within the soil.

The nitrogen component of the model simulates the processes of turnover of soil organic matter and crop residues and the associated mineralization and/or immobilization of nitrogen, hydrolysis of urea, nitrification, denitrification, floodwater biological activity and floodwater pH, ammonia volatilization, losses of nitrogen associated with runoff and percolation, and the uptake and use of nitrogen by the crop.

Validation

The CERES Rice V2.00 has been tested using data from Thailand, Hawaii, and the Philippines (IRRI). With the limited testing the model has reliably predicted the phenology, grain yield, and response to fertilizer over a wide range of growing seasons and for both upland and lowland rice. The model's response to applied nitrogen was tested with a line-source irrigation experiment conducted at IRRI with four rates of nitrogen (Figure 19). The comparison of observed and predicted changes in nitrogen content in the aboveground biomass over the growing season is presented in Figure 20. The validation of the model continues as part of collaborative effort between IRRI, IBSNAT, and IFDC.

The sensitivity of the model to nitrogen fertilizer application (applied as urea) and method of incorporating the fertilizer are illustrated in Figure 21. The simulated results highlight the benefits of deep-point placement of fertilizer, particularly at low input of nitrogen.

Example Simulation of Floodwater Component

The time course of various important floodwater properties can also be simulated. Such a simulation for an application made by broadcasting 50 kg nitrogen/ha directly into the floodwater without incorporation accurately described the rise in the amplitude of the daily fluctuation of floodwater pH followed by a period of reduced variation in floodwater pH. Shortly after fertilizer application, simulated algal activity rose, which is the predominant underlying cause of the changes in floodwater pH. Changes in floodwater ammoniacal nitrogen concentration and the simulated losses of nitrogen were also accurately depicted.

Work is continuing at IFDC on the development and validation of the model.

Release of Latest Versions of the CERES MODELS

The CERES wheat, maize, and sorghum models underwent substantial revision during 1988. The models now incorporate a standard user-friendly interface and graphics routines for displaying model outputs and validation results. To help new users in operating the models, a user's guide, providing step-by-step instructions, has been prepared for each model.

A user-friendly program, complete with an online help facility, for entering and organizing model input data is nearing completion. IFDC will be distributing the complete package of models, user's guides, and input program in 1989.

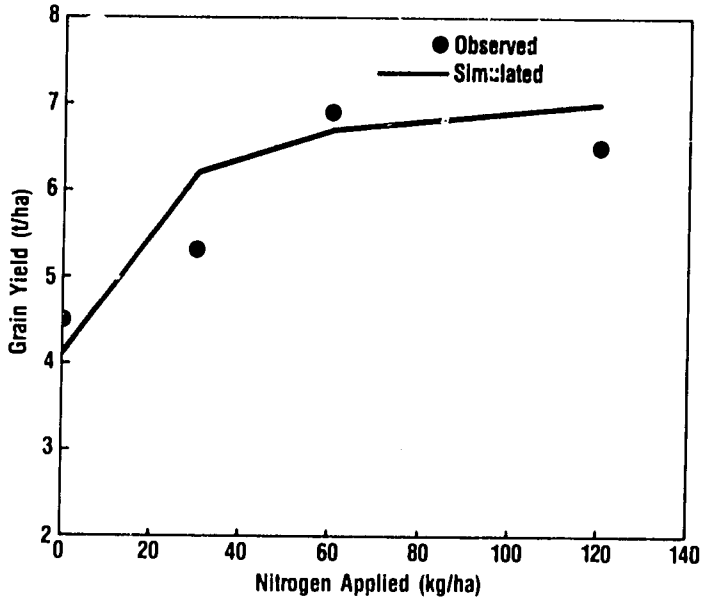


Figure 19. Comparison of Observed and Simulated Response to Nitrogen.

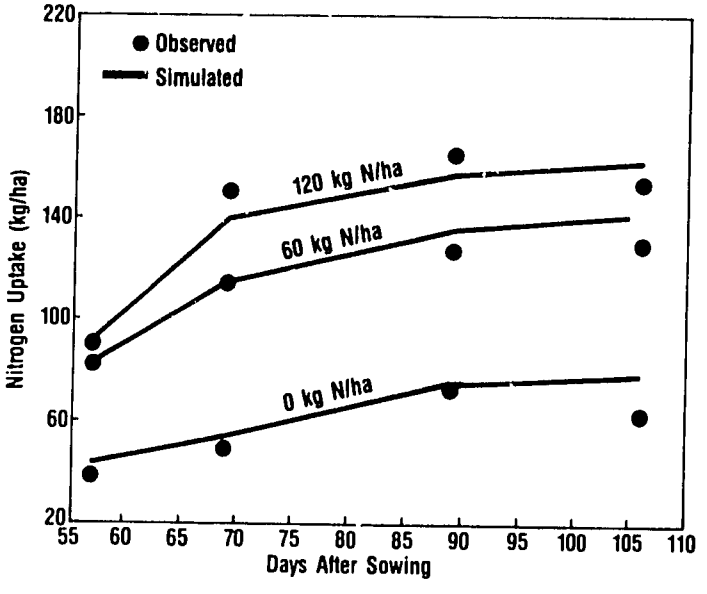


Figure 20. Comparison of Observed and Simulated Response to Nitrogen.

New Test for Phosphorus Fertility Evaluation

Of potential interest to agriculturists everywhere is the new soil phosphorus evaluation technique being developed and tested at IFDC. Based on the principle that phosphate ions are rapidly absorbed on the surface of oxides and hydroxides of iron on contact, this innovative technique makes use of strips of filter paper impregnated with iron oxides (P_i strips), as collectors to trap and remove the phosphorus from the soil solution. The method, the P_i soil phosphorus test (i denoting the iron oxide on the paper), is simple and reliable, and the technology is appropriate to developing countries.

To prepare the P_i strips, hardened filter paper is saturated with iron chloride by dipping it

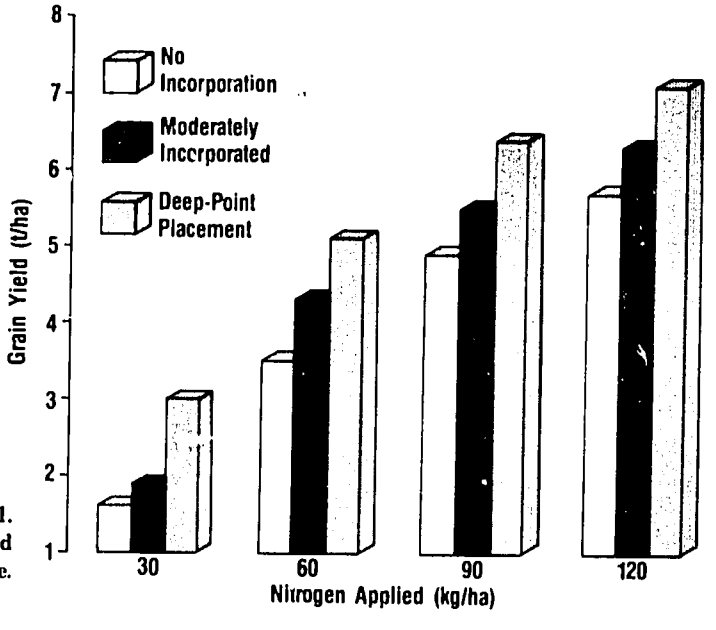


Figure 21. Simulated Grain Yield for Lowland Rice.

with iron chloride by dipping it in a 10% solution of the chemical in water, followed by drip drying and conversion of the chloride into oxides by exposure to ammonia vapor. The iron oxide-impregnated paper is then cut into strips 10 cm long and 2 cm wide.

Phosphorus in the soil is extracted by shaking a sample of the soil with a very dilute solution of calcium chloride and a P_i strip enclosed in a nylon gauze sheath overnight. The strip is taken out and the phosphorus retained is dissolved by shaking with dilute sulfuric acid for 1 hour. Phosphorus in the acid extract is measured by the molybdenum blue color method.

Tests carried out at IFDC have shown that the P_i soil phosphorus test has a good potential, especially in the phosphorus-deficient soils of the tropics. The method has certain advantages over the conventional soil tests now being used to evaluate phosphorus availability. The paper strips do not react with the soil, do not exert any harsh influence on the soil, or affect soil chemical equilibrium as the acid or alkaline extracting solutions do. The strips closely mimic the absorption by plant roots under natural conditions. Furthermore, unlike conventional soil testing methods in which acid reagents like Bray 1 or double acid is used to extract phosphorus from acid soils and alkaline solutions such as Olsen reagent is used for calcareous soils, the P_i test works equally well for acid, alkaline, or calcareous soils. In acid soils, P_i phosphorus has been found to give as good or better correlation with plant growth as Bray 1 P, and in calcareous soils the P_i test works as well as the Olsen test. Greenhouse studies have shown that across a wide range of soils, biomass yield of maize correlated best with the P_i phosphorus test and less so with the Olsen P or Bray 1 P.

Another feature of the P_i technology is that the test can evaluate phosphorus availability from soils treated with nonconventional phosphorus fertilizers. With the increase in the use of phosphate rocks and modified phosphate rocks such as PAPR, soil testing for phosphorus becomes more complex. The soil tests that are now being used may overestimate or underestimate phosphorus from soils treated with such materials. Research at IFDC has shown that the P_i test can give a reliable estimate of plant-available phosphorus from soils treated with natural or modified phosphates.

The P_i test is unique in that the P_i strips can be used not only to extract phosphorus from the soil in the laboratory, but they also have the potential to be used to extract phosphorus by direct application, either by embedding the strips in situ or by embedding them in soil columns. In a study, phosphorus extracted from several soils in Asia, Africa, and the United States by embedding P_i strips in soil columns was found to be very closely related to the amount of the nutrient measured in the laboratory.

Research on P_i technology is being continued at IFDC to calibrate the P_i test value with crop data under different soil, plant, and agroecological conditions and to expand the capabilities of its use for research and evaluation of phosphorus fertility.

Financial Report

2400 SouthTrust Tower
Birmingham, AL 35203-3296

Telephone 205 328 8700

Price Waterhouse

Report of Independent Accountants

March 22, 1989

To the Board of Directors of
International Fertilizer Development Center

In our opinion, the accompanying balance sheets and the related statements of revenue and expenses and changes in fund balances, of functional expenses and of cash flows present fairly, in all material respects, the financial position of International Fertilizer Development Center (IFDC) at December 31, 1988 and 1987, and the results of its operations, changes in its fund balances and its cash flows for the years then ended in conformity with generally accepted accounting principles. These financial statements are the responsibility of the organization's management; our responsibility is to express an opinion on these financial statements based on our audits. We conducted our audits of these statements in accordance with generally accepted auditing standards which require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements, assessing the accounting principles used and significant estimates made by management and evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for the opinion expressed above.

Price Waterhouse

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

ASSETS

CURRENT FUND

	December 31, 1988	December 31, 1987
Cash	$ 915,288	$ 349,497
Certificates of deposit	1,119,927	1,039,634
Amounts receivable from donors (Notes 1 and 2)	7,027,277	6,401,656
Other accounts receivable	1,627,557	699,246
Advances to employees	98,789	69,392
Supplies inventory (Note 1)	126,263	139,129
Prepaid expenses	248,637	182,665
	$11,163,738	$8,881,219

NONCURRENT FUND

	December 31, 1988	December 31, 1987
Amounts receivable from donors (Notes 1 and 2) - restricted	$1,110,172	$2,345,804

BUILDINGS AND EQUIPMENT FUND

(Note 1)

	December 31, 1988	December 31, 1987
Buildings	$5,868,910	$5,814,290
Equipment	5,190,330	5,069,410
Less - Accumulated depreciation	(6,152,255)	(5,818,308)
	$4,906,985	$5,065,392

LIABILITIES AND FUND BALANCES

CURRENT FUND

	December 31, 1988	December 31, 1987
Accounts payable	$ 512,066	$ 739,308
Accrued annual and sick leave	1,825,801	1,533,808
Deferred revenue (Notes 1 and 2)	7,765,290	6,229,176
Total liabilities and deferred revenue	10,103,157	8,502,292
Fund balance	1,060,581	378,927
	$11,163,738	$8,881,219

NONCURRENT FUND

	December 31, 1988	December 31, 1987
Deferred revenue (Notes 1 and 2) - restricted	$1,110,172	$2,345,804

BUILDINGS AND EQUIPMENT FUND

	December 31, 1988	December 31, 1987
Contract retainage	$ 215	$ 421
Lease obligation (Note 5)	85,456	12,669
Fund balance	4,821,314	5,052,302
	$4,906,985	$5,065,392

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1988 AND 1987

	Current Fund		Buildings and Equipment Fund		Total All Funds	
	1988	1987	1988	1987	1988	1987
Revenue:						
Grants (Note 2)	$ 8,496,430	$5,857,522		$ 130,751	$ 8,496,430	$5,988,273
Recovered project costs	2,888,667	2,281,865			2,888,667	2,281,865
Other	82,366	88,028			82,366	88,028
Total revenue	11,467,463	8,227,415		130,751	11,467,463	8,358,166
Expenses:						
Field programs (Note 3)	2,165,876	1,072,946	86,670	27,709	2,252,546	1,100,655
Research	3,483,505	3,320,344	305,175	434,864	3,788,680	3,755,208
Outreach	2,623,980	2,407,941	48,082	47,008	2,672,062	2,454,949
General and administrative	2,162,814	1,734,135	140,695	93,720	2,303,509	1,827,855
Total expenses	10,436,175	8,535,366	580,622	603,301	11,016,797	9,138,667
Excess (deficiency) of revenue over expenses	1,031,288	(307,951)	(580,622)	(472,550)	$ 450,666	($ 780,501)
Other changes in fund balances:						
Capitalized lease asset - net	(6,622)	(17,420)	6,622	17,420		
Equipment acquisitions from unrestricted funds	(330,343)	(225,719)	330,343	225,719		
Fund balances, beginning of period	366,258	930,017	5,064,971	5,281,713		
Fund balances, end of period	$ 1,060,581	$ 378,927	$4,821,314	$5,052,302		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1988 AND 1987

	Field Programs (Note 3)		Research		Outreach		Administrative		Total Expenses	
	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987
Personnel compensation (Note 4)	$ 770,903	$ 311,949	$1,941,135	$1,819,862	$1,279,717	$ 993,718	$1,143,867	$ 970,637	$ 5,135,622	$4,096,166
Personnel benefits (Note 4)	340,116	70,574	415,497	342,837	303,978	226,376	264,557	187,296	1,324,148	827,083
Travel and transportation	365,668	295,834	285,433	274,890	446,737	330,963	160,594	87,137	1,258,432	988,824
Occupancy	24,900	11,021	253,458	236,266	126,781	117,296	126,729	117,296	531,868	481,879
Telephone and telegraph	40,399	10,801	34,651	37,353	33,969	30,593	21,773	22,108	130,792	100,855
Rental of equipment	45,512	57,396	128	4,301		7,364	149	12,056	45,789	81,117
Contractual research and development	81,451	39,700	108,775	198,157		8,292	60,830	262	251,056	246,411
Other contractual services	184,434	91,852	198,102	187,925	179,426	268,475	61,653	67,985	623,615	616,237
Institute of International Education fee (Note 4)							164,693	134,414	164,693	134,414
Materials and supplies	282,353	164,939	191,215	158,846	196,846	376,019	131,368	105,840	801,782	805,644
Postage	8,835	3,743	21,665	19,335	26,903	18,580	10,327	8,962	67,730	50,620
Insurance	21,305	15,137	33,446	40,572	29,623	30,265	16,274	20,142	100,648	106,116
Miscellaneous			1,708				55,547	6,334	57,255	6,334
Total expenses before depreciation	2,165,876	1,072,946	3,485,213	3,320,344	2,623,980	2,407,941	2,218,361	1,740,469	10,493,430	8,541,700
Depreciation of buildings and equipment	86,670	27,709	303,467	434,864	48,082	47,008	85,148	87,386	523,367	596,967
Total expenses	$2,252,546	$1,100,655	$3,788,680	$3,755,208	$2,672,062	$2,454,949	$2,303,509	$1,827,855	$11,016,797	$9,138,667

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF CASH FLOWS

FOR THE YEARS ENDED DECEMBER 31, 1988 AND 1987

	For the Year Ended December 31, 1988	1987
Cash flows from operating activities:-		
Excess (deficiency) of revenue over expenses	$ 450,666	$ (780,501)
Adjustments to reconcile excess (deficiency) of revenue over expenses to net cash provided by operating activities:		
Depreciation	523,367	596,967
Other noncash charges	26,582	
Revenue recognized on donated asset		(130,751)
Loss on disposal or donation of equipment	39,380	6,334
Changes in assets and liabilities:		
(Increase) decrease in receivables from donors	610,011	(5,769,726)
(Increase) decrease in advances to employees	(29,396)	21,524
(Increase) decrease in other accounts receivable	(928,312)	461,120
Increase in prepaid expenses	(65,971)	(41,970)
(Increase) decrease in supplies inventory	12,866	(2,718)
Increase in accounts payable and accrued expenses	64,751	574,625
Increase in deferred revenue	300,482	5,599,782
Decrease in contract retainage	(206)	
Net cash provided by operating activities	1,004,220	534,686
Cash flows from investing activities:		
Capital expenditures	(330,343)	(225,719)
Net cash used in investing activities	(330,343)	(225,719)
Cash flows from financing activities:		
Principal payments under capital lease obligation	(27,794)	(17,420)
Net cash used in financing activities	(27,794)	(17,420)
Net increase in cash and cash equivalents	646,083	291,547
Beginning cash and cash equivalents	1,389,131	1,097,584
Ending cash and cash equivalents	$2,035,214	$1,389,131

Supplemental schedule of noncash investing and financing activities:

Capital lease obligations of $100,581 and $30,091 were incurred during 1988 and 1987, respectively, when the organization entered into leases for new equipment.

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

NOTES TO FINANCIAL STATEMENTS

NOTE 1 - ORGANIZATION AND ACCOUNTING POLICIES:-

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

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

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

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

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

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

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

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

E. For purposes of the statement of cash flows, IFDC considers certificates of deposit with an original maturity of three months or less to be cash equivalents.

NOTE 2 - GRANTS:-

Grants are summarized as follows:

	Year ended December 31,			
	1988		1987	
	Restricted	Unrestricted	Restricted	Unrestricted
Grants received -				
United States Agency for International Development (AID)	$ 2,725,000	$3,535,000	$2,430,934	$3,460,000
United Nations Development Programme (UNDP)			3,130,000	
International Development Research Centre (IDRC)			338,400	
Rockefeller Foundation	360,000			
Kellogg Foundation			1,462,500	
Directoraat Generalaal voor Internationale Samenwerking (Netherlands) (DGIS)	727,348		390,000	
World Bank	270,000		270,000	
Deutsche Gesellschaft fur Technische Zusammenarbeit				130,751
Der Bundesminister fur Wirschaftliche Zusammenarbeit (BMZ)	919,794			
	5,002,142	3,535,000	8,021,834	3,590,751
Amounts deferred during prior year	6,948,938	1,626,042	1,024,200	1,950,999
	11,951,080	5,161,042	9,046,034	5,541,750
Less - Amounts deferred to future periods	(7,102,020)	(1,490,000)	(6,948,938)	(1,626,042)
Other adjustments		(23,672)		(24,531)
Revenue recognized in current period	$ 4,849,060	$3,647,370	$2,097,096	3,891,177
		4,849,060		2,097,096
Total restricted and unrestricted		$8,496,430		$5,988,273

In addition to grant amounts deferred to future years, as indicated above, deferred revenue at December 31, 1988 includes $283,442 of cash collected on reimbursable cost projects for which revenue has not been recognized.

The unrestricted grants from AID provided funds of $3,535,000 and $3,460,000 during the fiscal years ending June 30, 1989 and 1988, respectively.

During 1988, IFDC received several restricted grants relating to work in Africa. DGIS awarded an additional $727,348 to be used for the Togo Center. In 1988 IFDC received two restricted grants from BMZ. One grant, for $325,162, is restricted to development of the Togo Center, and the second, for $594,632, is restricted to research for underdeveloped phosphate deposits in West Africa and expires in March 1990. In 1988 the Rockefeller Foundation awarded $360,000 to be used for fertilizer research in West Africa. This grant expires March 31, 1991. Also, in 1988 the World Bank Organization awarded $270,000 to be used for the Togo Center.

Other restricted grants received were similarly restricted by the grantor as to specific projects and/or geographic regions. The IDRC grant of $338,400 received during 1987 is restricted to fertilizer research in West African environments and is due to expire March 31, 1989. The grant stipulates that unexpended funds will be returned to the grantor after completion of the project.

In 1987 UNDP awarded $130,000 to be used in completing Phase II of a research and training project. Subsequently, UNDP awarded a $3,000,000 grant which extended Phase II beyond June 30, 1987 to December 31, 1990. This grant allowed for continuation of Phase II and provided funds for preparatory work for the African Fertilizer Center in Togo. Three other grants received during 1987, $1,462,500 from the Kellogg Foundation, $390,000 from DGIS and $270,000 from the World Bank Organization were restricted to use in the development of the African Center in Togo.

During 1987, IFDC received four restricted grants from AID. One grant for $224,434 concentrated on fertilizer research and training in Niger and expired in November 1988. The second, for $140,000, provides support for IFDC's project entitled "The Development of the Nitrogen Component of the Ceres Rice Model." The third grant, for $1,080,000, provides support for IFDC's program to conduct specific fertilizer research in West Africa, and the expiration date is July 31, 1992. The final restricted AID grant received during 1987 provides funds of $986,500 over a 5 year period ending July 3, 1992; these funds are to be used for a research project in tropical Africa. In 1988, AID awarded an additional $1,620,000 for fertilizer research in West Africa and an additional $1,105,000 for the research project in tropical Africa. For all restricted AID grants, the contracts require that unexpended funds be returned to the grantor at the completion of the contract.

Receivables from donors at December 31, 1988 and 1987 are summarized as follows:

	December 31,			
	1988		1987	
	Restricted	Unrestricted	Restricted	Unrestricted
AID	$3,380,496	$1,490,000	$2,300,762	$1,850,172
DGIS	440,911		390,000	
UNDP	1,549,046		2,956,267	
IDRC	165,617		266,690	
Rockefeller Foundation	240,000			
Kellogg Foundation	475,000		962,500	
BMZ	396,379			
Ford Foundation				21,069
	6,647,449	1,490,000	6,876,219	1,871,241
Less - noncurrent portion	1,110,172		2,345,804	
	$5,537,277	1,490,000	$4,530,415	1,871,241
		5,537,277		4,530,415
Total restricted and unrestricted		$7,027,277		$6,401,656

NOTE 3 - AFRICAN FERTILIZER CENTER IN TOGO:

IFDC established permanent field programs in Togo, Africa, during 1987. Because programs based in the field are new to IFDC, such operations constitute a new functional classification.

NOTE 4 - INSTITUTE OF INTERNATIONAL EDUCATION:

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

NOTE 5 - CAPITALIZED LEASE OBLIGATIONS:-

IFDC leases office equipment under agreements classified as capital leases. Assets recorded under capital leases are included in property and equipment as follows:

	December 31,	
	1988	1987
Office Equipment	$130,672	$30,091
Less: accumulated depreciation	19,040	8,150
	$111,632	$21,941

As of December 31, 1988, future minimum lease payments are as follows:

1989	$35,104
1990	21,126
1991	21,126
1992	21,126
	98,482
Less: amounts representing interest	13,026
Present value of minimum lease payments	$85,456

1988 IFDC Publications

The following are publications released by IFDC during 1988. A complete list of IFDC publications is available upon request.

Proceedings

Workshop on Fertilizer Sector Development and Agricultural Production in Selected Countries of Mediterranean, Middle East, and North Africa, Proceedings, E. C. Kapusta (1988). (SP-8)*

NPK Fertilizer Production Alternatives, United States, J. J. Schultz; US $50, elsewhere, US $60 (1988). (SP-9)*

Paper Series

A Socioeconomic Study of Farm-Level Constraints to Fertilizer Use in Western Niger, Thomas P. Thompson (1988). (P-6)*

Agronomic Evaluation of PAPR in the Tropics: IFDC's Experience, S. H. Chien and L. L. Hammond (1988). (P-7)*

Promotional Booklets

IFDC—Providing Technical Services to the Developing World, Marie K. Thompson; free of charge (1988). (G-6)

Journal Articles

(Nitrogen)

Savant, N. K., A. F. James, G. E. Peters, and R. Medina. 1988. "Evaluation of Phenoxyaminocyclotriphosphazatrienes as Sustained-Action Soil Urease Inhibitors," *Journal of Agricultural and Food Chemistry,* 36(2):390-392. (B-96)*

Peters, G. E., R. J. Radel, and R. Medina. 1988. "Synthesis of Phenoxyaminocyclotriphosphazatrienes," *Journal of Agricultural and Food Chemistry,* 36(2):384-390. (B-97)*

Katyal, J. C., B. Singh, and P.L.G. Vlek. 1988. "Effect of Granule size and Placement Geometry on Efficiency of Urea Supergranules for Wetland Rice Grown on a Permeable Soil," *Fertilizer Research,* 15:193-201. (B-98)*

Buresh, R. J., and E. R. Austin. 1988. "Direct Measurement of Dinitrogen and Nitrous Oxide Flux in Flooded Rice Fields," *Soil Science Society of America Journal,* 52(3):681-687. (B-99)*

Buresh, R. J., S. K. De Datta, J. L. Padilla, and M. I. Samson. 1988. "Effect of Two Urease Inhibitors on Floodwater Ammonia Following Urea Application to Lowland Rice," *Soil Science Society of America Journal,* 52(3):856-861. (B-100)*

Snitwongse, P., A. Satrusajang, and R. J. Buresh. 1988. "Fate of Nitrogen Fertilizer Applied to Lowland Rice on a Sulfic Tropaquept," *Fertilizer Research,* 16:227-240. (B-101)*

Buresh, R. J., S. K. De Datta, J. L. Padilla, and M. I. Samson. 1988. "Field Evaluation of Two Urease Inhibitors With Transplanted Lowland Rice," *Agronomy Journal,* 80(5):763-768. (B-102)*

Christianson, C. B.; M. F. Carter; and L. S. Holt. 1988. "Mineralization and Nitrification of Urea-form Fertilizers," *Fertilizer Research,* 17:85-95. (B-103)*

Holt, L. S., C. B. Christianson, E. R. Austin, and J. C. Katyal. 1988. "A Laboratory Technique for Releasing and Measuring Denitrification Products Trapped in Soil," *Soil Science Society of America Journal,* 52(5):1510-1511. (B-104)*

Katyal, J. C., M. F. Carter, and P.L.G. Vlek. 1988. "Nitrification Activity in Submerged Soils and Its Relation to Denitrification Loss," *Biology and Fertility of Soils,* 7:16-22. (B-105)*

Buresh, R. J., S. K. De Datta, J. L. Padilla, and T. T. Chua. 1988. "Potential of Inhibitors for Increasing Response of Lowland Rice to Urea Fertilization," *Agronomy Journal,* 80(6):947-952. (B-106)*

Christianson, C. B. 1988. "Factors Affecting N Release of Urea from Reactive Layer Coated Urea," *Fertilizer Research,* 16:273-284. (B-107)*

DeDatta, S. K., R. J. Buresh, M. I. Samson, and Wang Kai-Rong. 1988. "Nitrogen Use Efficiency and Nitrogen-15 Balances in Broadcast-Seeded Flooded and Transplanted Rice," *Soil Science Society of America Journal,* 52(3):849-855. (B-108)*

Savant, N. K., and O. W. Livingston. 1988. "Urea Supergranules: An Appropriate Urea Fertiliser for Small Rice Farmers of Developing Countries," *Fertiliser News,* 33(10):33-37. (B-113)*

Savant, N. K. 1988. "Dispenser Method for Using Urea Supergranules in Transplanted Rice," *International Rice Research Newsletter,* 13(4):44-45. (B-114)*

Savant, N. K., A. F. James, and G. H. McClellan. 1988. "Effect of Soil Bulk Density on Inhibition of Hydrolysis of Surface-Applied Granular Urea Containing Phenyl Phosphorodiamidate in Unsaturated Soil," *Communications in Soil Science Plant Analysis,* 19(2):193-204. (B-115)*

Schultz, James J. 1988. "Experience With Using Urea in the Production of Granular Compound (NPK) Fertilisers," *International Symposium on Urea Technology and Utilisation, Proceedings,* pp. 295-310, Malaysian Society of Soil Science, Kuala Lumpur, Malaysia. (B-126)*

J. Sri Adiningsih S., M. Sudjadi, and Ray Diamond. 1988. "Comparison of Deep Placement Urea Supergranules and Broadcast Urea on the Yield of Rice on Vertisols of Indonesia," *International Symposium on Urea Technology and Utilisation, Proceedings,* pp. 201-216, Malaysian Society of Soil Science, Kuala Lumpur, Malaysia. (B-127)*

(Phosphate)

Van Kauwenbergh, S. J., M. Cooper-Fleck, and M. R. Williams. 1988. "The Occurrence of Robertsite in a Sedimentary Phosphate Ore From Thailand," *Mineralogical Magazine,* 52:505-508. (C-71)*

(Miscellaneous)

Youngdahl, Leif. 1988. "Method for the Estimation of Nutrient Uptake Kinetic Parameters Using Nonparametric Statistics," *Journal of Plant Nutrition,* 11(3):321-331. (D-84)*

Parish, Dennis H. 1988. "Sustaining Yields With Properly Balanced Inputs," *Custom Applicator,* April, pp. 54-62. (D-86)*

Giroti, R. S., and D. H. Parish. 1988. "IFDC Training Programs," Presented at the International Agricultural Research Centers' Workshop on Human Resource Development Through Training, International Potato Center, Lima, Peru. (D-89)*

Stangel, P. J. 1988. "The Role of Fertilizer in Fostering Economic Development in Sub-Saharan Africa," Presented at Workshop on Transfer of Fertilizer Technology, September 28-30, 1988, Lomé, Togo. (D-91)*

Stangel, P. J. 1988. "Factors Affecting Fertilizer Exports to Asia: A 1989 Perspective," Presented at Fertilizer Outlook 1989, Sponsored by The Fertilizer Institute, November 30-December 1, 1988, Washington, D.C. (D-92)*

Rhodes, E. R. 1988. "Africa—How Much Fertilizer Needed: Case Study of Sierra Leone," *Fertilizer Research*, 17:101-118. (D-94)*

(Sulfur)

Chien, S. H., L. K. Friesen, and B. W. Hamilton. 1988. "Effect of Application Methodology on Availability of Elemental Sulfur in Cropping Sequences," *Soil Science Society of America Journal*, 52:165-169. (E-9)*

Friesen, Dennis K. 1988. "Sulphur Fertilizer Research at IFDC," *Sulphur in Agriculture*, 12:14-18. (E-12)*

Katyal, J. C., D. K. Friesen, and P.L.G. Vlek. 1988. "Deficiencies of Micronutrients and Sulfur in Wheat," IN *Wheat Production Constraints in Tropical Environments*, pp. 99-129, Proceedings of an International Conference, Chiang Mai, Thailand. (E-13)*

*US $4.00 for U.S. addresses; US $7.50 for overseas addresses.

IFDC Board of Directors

(as of December 31, 1988)

Chairman

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

Vice Chairman

Dr. David Hopper
Senior Vice President for
Policy, Planning, and Research
The World Bank
Canada

Mr. Yaovi Adodo
Minister of Foreign Affairs
and Cooperation
Togo

Dr. Eliseu Roberto de Andrade Alves
President
CODEVASF
Brazil

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

Dr. Hiram Grove V.
Director
INIA's Agricultural Technical Journal
Chile

Dr. Samuel C. Muchena
Deputy Secretary
Planning and Technical Service
Ministry of Lands, Agriculture, and
Rural Development
Zimbabwe

Mr. Pratap Narayan
Executive Director
Fertiliser Association of India
India

Dr. Christian Pieri
Deputy Director
Soils-Direction des Resources Naturelles
IRAT/CIRAD
France

Dr. Bukar Shaib
Former Minister of Agriculture
Nigeria

Dr. Pieter van Burg
Director
Netherlands Fertilizer Institute
The Netherlands

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

Mr. Joe Wheeler
Chairman
Development Assistance Council
U.S.A.

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

Ex Officio Member

Dr. Donald L. McCune
Managing Director
IFDC

Ex Officio Member

Marjorie R. Brashier
Administrative Director
IFDC

Staff

Office of the Managing Director

Donald L. McCune, Managing Director
Paul J. Stangel, Deputy Managing Director
Marjorie R. Brashier, Administrative Director
Debra R. Rutland, Executive Secretary
Amber N. Hammock, Correspondence Secretary
Kaye F. Barker, Budget Officer
Jacqueline A. Berrens, Assistant Librarian
Charles E. Butler, Photographer/Media Technician
Glenda Carter, Accounting Clerk
Linda B. Cornatzer, Word Processing Specialist
Mary E. Dorman-Taylor, Word Processing Specialist*
C. David Edwards, Personnel Officer
Brenda S. Elmore, Word Processing Specialist
Ernest D. Frederick, Technical Editor
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
Vickie J. Hollandsworth, Word Processing Specialist
W. Diane Kasmeier, Assistant Purchasing Agent
James M. Kelly, Purchasing Agent
Terry L. McGee, Graphic Artist/Media Technician
Jean G. Meyer, Mail Clerk
Brenda G. Peden, Accounting Clerk
Faye Predmore, Receptionist
Jean S. Riley, Librarian
Elizabeth N. Roth, Editor
Flora M. Rudolph, Technical Illustrator
Patricia F. Sandlin, Word Processing Specialist
Debra S. Shedd, General Accountant
Carol F. Slaton, Word Processing Specialist
Patricia H. Spires, Clerk
Henry Ssali, Soil Scientist
James C. Starkey, Graphic Designer/Illustrator
Marie R. Stribling, Coordinator, Word Processing Center
Joy M. Thompson, Accounting Clerk
Marie K. Thompson, Communications Supervisor
Michael O. Thompson, Visitor Relations Officer
Donna W. Venable, Word Processing Specialist
Gwendolyn A. Watts, File Clerk**
Lewis B. Williams, Liaison Scientist
David B. Wright, Mail Clerk
Tommy L. Wright, Photographer/Media Technician*
Lynda F. Young, Editor

Agro-Economic Division

Lawrence L. Hammond, Director
Mary C. Irons, Administrative Secretary
Nancy A. Potter, Correspondence Secretary
Bodh R. Arora, Visiting Scientist*
Ernest R. Austin, Instrumentation Specialist
Carlos A. Baanante, Economist
Walter E. Baethgen, Soil Scientist/Biometrician
Karen S. Billingham, Laboratory Supervisor
Roland J. Buresh, Soil Scientist
Kristi L. Burghed, Chemical Laboratory Analyst
Bernard H. Byrnes, Soil Scientist
Jenny C. Calabio, Visiting Scientist*
Angel Calvo-Herrera, Visiting Scientist*
Gildardo Carmona, Visiting Scientist*
Michael F. Carter, Research Associate*
Sen H. Chien, Soil Chemist
C. Bruce Christianson, Soil Scientist
John T. Colagross, Electronics Specialist
Jeanene G. Daniels, Chemical Laboratory Analyst
Michael R. Ezell, Chemical Laboratory Analyst*
Ronnie L. Faires, Greenhouse Supervisor
Dennis K. Friesen, Soil Scientist
Douglas C. Godwin, Agronomist/Systems Modeller
Celia J. Guinn, Chemical Laboratory Analyst
Deborah T. Hellums, Research Associate
Julio Henao, Biometrician
Vaughn K. Henry, Greenhouse Technician
Leella S. Holt, Research Associate
Carla G. Humphries, Computer Operator/Programmer
Angela F. James, Chemical Laboratory Analyst*
George T. Jones, Jr., Student Worker
Jagdish C. Katyal, Visiting Scientist*
Raymond H. Kluesner, Student Worker*
Linda G. Counts, Computer Operator/Programmer
L. Alfredo León, Soil Scientist
Raman G. Menon, Soil Scientist
Angela S. Pickens, Chemical Laboratory Analyst
Brian D. Riley, Student Worker
Surjit Sidhu, Economist
Upendra Singh, Systems Modeller/Soil Scientist
John P. Skipworth, Laboratory Technician*
M. Patricia Stowe, Research Assistant
John M. Stumpe, Research Associate*
B. Keith Tays, Chemical Laboratory Analyst
Kerry M. Thomas, Greenhouse Technician*
Thomas P. Thompson, Rural Sociologist
Dixing Yin, Visiting Scientist
Leif J. Youngdahl, Crop Physiologist

Fertilizer Technology Division

Owen W. Livingston, Director
Delilah A. Forsyth, Administrative Secretary
Frances H. Glover, Correspondence Secretary
Sherry R. Bayless, Student Worker
Billy W. Biggers, Jr., Analytical Chemist
Bobby W. Biggers, Chemist
George W. Bolds, III, Pilot-Plant Operations Coordinator
Robert C. Bosheers, Engineering Research Technician
Margaret M. Chien, Technical Aide
Jerry R. Clemmons, Chemist
Kenneth W. Collins, Student Worker
Doyce E. Couch, Assistant Maintenance Coordinator
Norbert G.H. Engel, Visiting Scientist*
Nathan A. Engle, Maintenance Technician***
Thomas E. Evers, Technical Aide
Michael D. Hellums, Maintenance Technician
Gary L. Hines, General Helper
Macy W. Hitson, Technical Aide*
Vanessa E. Keel, Chemical Laboratory Analyst
Talaat A.B. Lawendy, Minerals Engineer
Jose R. Lazo de la Vega, Special Project Engineer
Benjamin C. Malone, Engineering Research Technician
Guerry H. McClellan, Research Coordinator
T. Alan Nix, Assistant Pilot-Plant Operations Coordinator
G. Erick Peters, Chemist
Jorge R. Polo, Engineering Coordinator
H. Dale Richards, Warehouse Technician
Johnnie W. Riley, Maintenance Coordinator
Amitava H. Roy, Special Project Engineer
David W. Rutland, Physical Properties Specialist
Narayan K. Savant, Soil Chemist (Nitrogen)
Xiao Bing Tong, Visiting Scientist
Steven J. Van Kauwenbergh, Mineralogist/Petrographer

Outreach Division

Dennis H. Parish, Director
Deborah B. King, Administrative Secretary
Daris H. Belew, Correspondence Secretary
Evelyn Freeman, Secretary
Ann H. Mock, Correspondence Secretary
Loren E. Ahlrichs, Marketing Specialist
John H. Allgood, Market Analyst
Balu L. Bumb, Economist
Yao H. Chuang, Market Development Economist
W. Edward Clayton, Transportation/Distribution Specialist
Ray B. Diamond, Coordinator, Fertilizer Evaluation Unit
Ram S. Giroti, Training Administrator
D. Ian Gregory, Marketing Specialist
Regina S. Harris, Marketing Research Assistant
Edwin C. Kapusta, Regional Coordinator—Asia
Zahedur R. Kazi, Project Liaison Officer
Nam D. Le, Chemical Engineer
Vincent E. Leon, Fertilizer Production Specialist
Adolfo Martinez, Agricultural Economist
William F. Mattison, Credit Specialist
Kenneth L. Moots, Marketing Consultant
James J. Schultz, Fertilizer Production Specialist
Glenda F. Smallwood, Marketing Research Assistant
Linda W. Trousdale, Information/Marketing Associate
Larry L. Vance, Training Assistant
Regina L. Young, Student Worker

IFDC-Africa

Paul L.G. Vlek, Director—IFDC-Africa
Komi Adzomada, Administrative Officer
Martine Bassery, Administrative Officer
Yanick Nicolas, Administrative Secretary
Konadu Acheampong, Visiting Scientist[a]
Ketline Adodo, Associate Editor
Andre M. Bationo, Soil Scientist
Michael M. Connolly, Head of Communications
Rein Coster, Market Analyst
M. Terry Frederick, Engineering/Training Coordinator
Ampah K.C. Johnson, Associate Geologist
John P.A. Lamers, Extension Agronomist
A. Uzo Mokwunye, Coordinator-Agronomic Research
Hans Werner Muller, Soil Scientist[b]
Joseph G. Nagy, Economist
Ahli K. Pinto-Tbyi, Associate Soil Scientist
Edward R. Rhodes, Agronomist
Jacob F. Teboh, Agricultural Economist

*Left in 1988.
**Retired in 1988.
***Deceased.

a. Rockefeller Fellow
b. Seconded to IFDC by Bundesanstalt für Geowissenschaften und Rohstoffe

IFDC Addresses

(as of July 1989)

Headquarters

IFDC
P.O. Box 2040
Muscle Shoals, Alabama 35662
U.S.A.
Telephone: 205-381-6600
Telex: 810-731-3970
Telefax: 205-381-7408

Other IFDC OFFICES

IFDC/Dhaka
GPO 3044
Dhaka
BANGLADESH
Telephone: 259642/281508
Telefax: 880-2-411-079

IFDC/CIAT
Apartado Aéreo 6713
Cali
COLOMBIA
Telephone: 57:23-675050
Telex: 05769 CIAT CO.ITT
Telefax: 57:23-647243

IFDC/CSR
Centre for Soil Research
Jln. Ir. H. Juanda 98
Bogor
INDONESIA
Telephone: 251-311256
Telex: 48572 CSR IA

IFDC/ICRISAT Sahelian Center
BP 12404
Niamey
NIGER
Cable: ICRISAT, Niamey
Telex: 5406 NI
Telephone: 722529/722725/723697

IFDC/IRRI
P.O. Box 933
Manila
PHILIPPINES
Telephone: 88-48-69/88-45-14
Telex: ITT 45365 RICE INST PM
Telefax: 63-2-8178470

IFDC-Africa
B.P. 4483
Lomé
TOGO
Telephone: 21-79-71
Telex: 5416 CIFDC TG
Telefax: 21-78-17

IFDC/SADCC/ICRISAT
P.O. Box 776
Bulawayo
ZIMBABWE
Telephone: 79563
Telex: 3570 ZIMBABWE
Cable: MATGRIC, Bulawayo
Telefax: 76658

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

Phone No. 205-381-6600
TWX-810-731-3970 IFDEC MCHL
Telefax: (205)381-7408

ISSN-0748-5875

Edited by Marie K. Thompson/Draft Typing, Donna W. Venable/Typesetting, Patricia F. Sandlin/Layout and Graphics, James C. Starkey. Photo Credits: J. H. Allgood, p. 48; Dr. R. Buresh, p. 31; C. L. Butler, cover, pp. i, iv, 54; M. Connolly, pp. 10, 17; Dr. R. B. Diamond, p. 39; C. R. Dowswell, p. iii (bottom); M. T. Frederick, pp. 12, 13; R. S. Giroti, p. 49; Dr. A. Martinez, p. 52; Luis Guillermo Restrepo, pp. v (bottom), 41, 46; Dr. E. R. Rhodes, p. 21; Dr. T. P. Thompson, pp. ii, vi, vii, viii, 5, 8, 28; L. B. Williams, p. 23; T. L. Wright, pp. iii (top), v (top).