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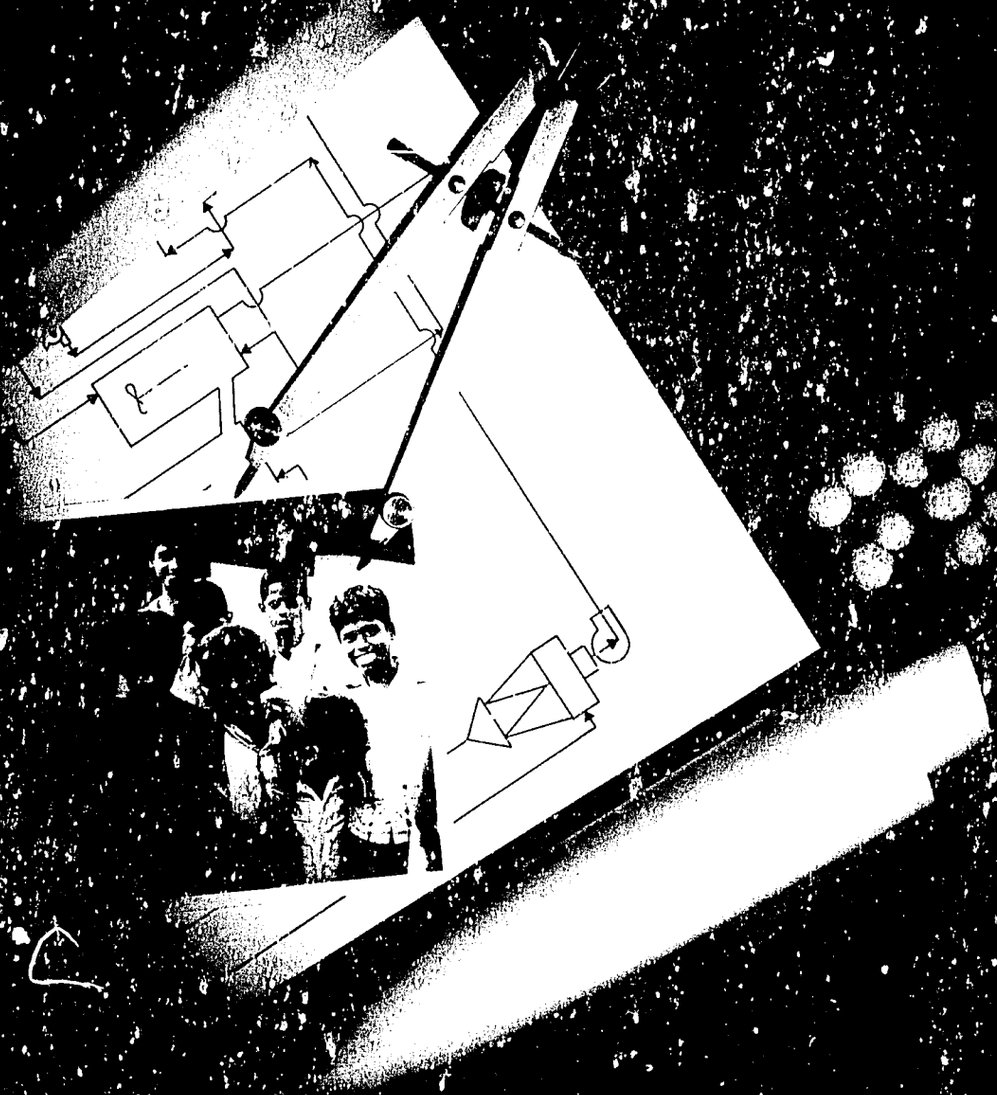

"Drafting a Blueprint for Tomorrow"

Management Perspective

The process of "drafting a blueprint for tomorrow" has proven to be a very valuable exercise for IFDC, and we will continue to realize its benefits in the future.

Dr. David Hopper of our Board of Directors (also Senior Vice President for Policy, Planning, and Research of the World Bank) has referred to the newly formulated IFDC Ten-Year Plan as "a vote of confidence regarding where the Center has been—the progress that has been made."

Because of the changing needs and emphasis of world agriculture and fertilizer environments, our Board of Directors felt that a program plan for the next 10 years should be developed to identify IFDC's priorities in the areas of research, technology transfer, and information dissemination. The Plan is viewed as a general guide to orient the future direction of the Center's efforts. We look forward with enthusiasm to the next 10 years; this should prove to be an exciting era in the history of the institution.

During 1987 IFDC expanded its impact with the establishment of a regional base of operation on African soil. With the help of the Togolese Government, IFDC set up its West Africa Division in Lomé, Togo. We will now be able to better serve the fertilizer development needs of West Africa from this vantage point. The staff members of our West Africa Division have mounted research and training programs in three broad areas of agronomy, economics, and resource development.

As IFDC continues to expand, we realize that if we are to be truly effective we must focus on the human aspect by improving the quality of life of the ultimate beneficiaries of our work—the people of developing countries. Toward this end, we have engaged the collaboration and cooperation of the people of developing countries on every level. National scientists, extension workers, key specialists from the fertilizer industry, administrators, and farmers themselves are now active participants in the work of IFDC. By viewing their research through farmers' eyes, our scientists can make their work much more appropriate and, thus, useful in a particular situation and more valuable in the end.

"If you desire peace, cultivate justice, but at the same time cultivate the fields to produce more bread; otherwise, there will be no peace."

Dr. Norman Borlaug
Nobel Peace Prize
Acceptance Speech
December 11, 1970

Donald L. McCune
Managing Director

Paul J. Stangel
Deputy Managing Director

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Drafting a Blueprint for Tomorrow

During the past 12 years, the International Fertilizer Development Center has made significant progress in identifying agronomic, technological, and economic constraints to fertilizer use as well as removing these in order to increase and sustain food production in developing countries.

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, and at least two of these technologies are now ready for more extensive evaluation in specific agroclimatic and economic zones of developing countries.

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 or extended phosphates may be appropriate alternatives in developing countries. Data base development and research on the use of computer simulation modeling has also led to expanded capabilities in extrapolation of research results in the area of nutrient use efficiency. These technologies are also ready for direct transfer to specific agroeconomic zones.

Beyond these developments, IFDC has made significant progress in making the fertilizer sector in developing countries more efficient through training, technical assistance, and country-specific studies. In carrying out its mission, IFDC has developed important linkages and integrated programs with national and international institutions.

The world agricultural and fertilizer situations have drastically changed since 1975, when the IFDC mandate and objectives were established. The fertilizer shortages and high prices of the mid-1970s caused many developing countries to seek, evaluate, and develop indigenous resources of fertilizer raw materials, while emphasizing the need for increasing fertilizer use efficiency. At the present time the global shortages and high prices of fertilizers of the previous decades have been replaced by surpluses and low prices. Much of this has been due to expanded production from a more diverse source of supply. The changes have prompted many developing countries to shift priorities in their agricultural development, including those of the fertilizer sector.

Beyond these developments, IFDC has made significant progress in making the fertilizer sector in developing countries more efficient through training, technical assistance, and country-specific studies. In carrying out its mission, IFDC has developed important linkages and integrated programs with national and international institutions.

The food supply situation has generally improved in Asia and Latin America in the past 12 years. In contrast, the situation in tropical Africa has rapidly deteriorated, precipitating a catastrophic food shortage in 1983/84. Most developed countries and international donors responded through food aid—a situation that has only been partially remedied. However, the donor community recognized this assistance to be a short-term solution and has planned long-term strategies to avert such calamities through more research on food crops with emphasis on soil fertility, fertilizer use, and crop varieties.

Recognizing that IFDC must refocus its efforts to accommodate the changing needs and emphasis of the world agriculture and fertilizer environments, the Center's Board of Directors, during its

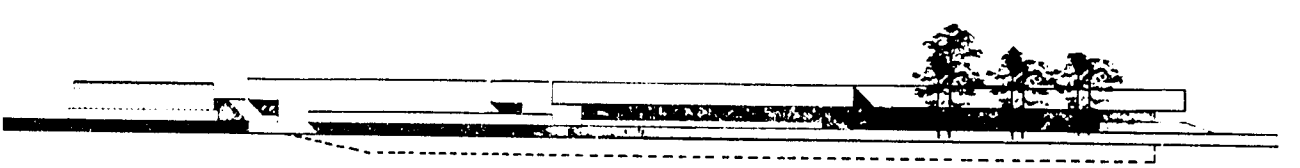
1986 meeting, recommended that a program plan be developed to identify the Center's priorities fc the next 10 years. These priorities were to focus on the areas of research, technology transfer, and information dissemination that would be relevant to the needs of the developing countries through the remainder of this century.

To develop this program plan, Dr. Donald L. McCune, IFDC's Managing Director, appointed a committee composed of the various disciplines represented on the staff—engineers, soil scientists, economists, marketing specialists, training specialists, and others. The program plan developed by the committee includes recommendations for the future directions of the Center in (1) research and development covering production technology, agronomy, economic and social sciences, and development of database and information systems; (2) technology transfer covering technical assistance and training; (3) information dissemination; (4) organizational development; (5) linkages; and (6) funding. These recommendations are based on IFDC's mandate, its accomplishments, and the influence that present world agriculture, fertilizer situations, and future expectations can have on the fertilizer technology needs of developing countries.

Recognizing that IFDC must refocus its efforts to accommodate the changing needs and emphasis of the world agriculture and fertilizer environments, the Center's Board of Directors, during its 1986 meeting, recommended that a program plan be developed to identify the Center's priorities for the next 10 years.

IFDC's mandate to focus on research, development, and transfer of appropriate fertilizer technology and related know-how for increasing food and agricultural production in developing countries at the lowest possible cost will continue during the next 10 years. However, the Center's scope of work and program emphasis should be modified to complement changes in the climate of world agriculture. The main factors expected to affect the role of fertilizer in developing countries and thereby have a direct impact on IFDC programs during the next 10 years are as follows:

1. A limited potential for expansion in arable land and area irrigated exists, particularly in the densely populated regions of the developing world.
2. A number of countries, especially in Latin America and sub-Saharan Africa, are facing serious problems of unemployment and limited availability of foreign exchange with the burden of rapidly escalating foreign debts.
3. Despite significant increases in the adoption and use of fertilizers in developing countries during the past decade, great potential still exists for expanding food production through the increased use of fertilizers in most countries of sub-Saharan Africa, Latin America, Asia, the Middle East, and North Africa.
4. In addition to significant differences in resource endowments, institutional strengths, and levels of development among countries, surpluses and depressed prices of agricultural products and fertilizers in the world market have been observed in conjunction with serious regional and intraregional disparities during the past 2-3 years.
5. As a result of balance-of-payment problems in developing countries and the related scarcity of foreign exchange, export crops and import substitutions are becoming increasingly important.
6. The rapid development of communication technology and information systems of the last few years is expected to continue during the next decade.



7. Increased production without ample attention to the careful use of inputs and soil conservation measures are causing environmental degradation in lands of some areas of the developing countries.

Recommended Activities

Research and Development

IFDC is recognized as a basic source of information on the phosphate deposits of the world. This information base should be expanded to include other fertilizer raw materials such as potash, sulfur, and limestone. Information on secondary and micronutrients should also be added to the information base by the year 2000. In addition, linkages should be established with institutions gathering data on natural gas and coal, and strategies should be developed to bring the information to the raw material data file. Economic studies are needed to determine the optimum process conditions for impurity removal and recovery of the primary nutrients, i.e., phosphate, potash, and sulfur. Process development work is needed on some problem ores to minimize water consumption.

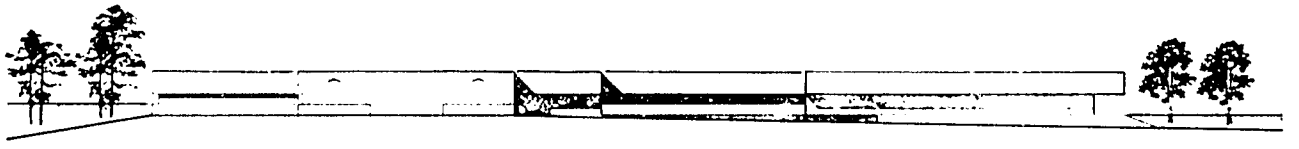
As in the case of phosphate, IFDC has also established itself internationally as a leader in the technology of identifying nitrogen losses and developing means to curb these losses. Work at IFDC has shown that high technology coatings on urea have a good agronomic potential. The results on controlling urea dissolution, decreasing nitrogen losses, and increasing plant nitrogen uptake are encouraging. However, environmental concerns rather than economic and agronomic efficiencies are the factors that should justify the development of these products for general agricultural use over the next 10 years. The development of "layered" coatings may also permit the incorporation of trace and secondary elements, pesticides, and herbicides in the same granule.

IFDC is recognized as a basic source of information on the phosphate deposits of the world. The Center has also established itself internationally as a leader in the technology of identifying nitrogen losses and developing means to curb these losses.

Recent studies on technology have indicated that environmental issues will be of growing concern in developing countries in the next decade. IFDC should maintain and expand its capabilities in pollution measurements as well as control methods and practices to reduce potential hazards.

New developments in the Center's program should include new fertilizer products and intermediates, biotechnology, and recycling of domestic and agricultural wastes. The focus of agronomic research should be expanded to address the issues of the sustainability of crop production, fertilizer management, long-term strategies to improve returns to farmers, resource conservation, and environmental concerns.

Socioeconomic research is needed to effectively identify fertilizer technologies that can increase farmers' economic benefits and be adopted to expand crop yields, increase land and labor productivities, promote agricultural development, and generally enhance food production capacity.



Technology Transfer

IFDC should continue its technology transfer activities through its technical assistance and training activities. In implementing technology transfer programs, IFDC should recognize physical, social, economic, and political constraints associated with the transfer of technology.

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Technical Assistance—IFDC should continue to render technical assistance in fertilizer use evaluation, production technology, marketing, and special projects. During the next decade IFDC's fertilizer use evaluation activities should concentrate on:

1. Identifying regions and/or specific developing countries where inefficient fertilizer use is a key constraint to agricultural development.
2. Developing a multidisciplinary network of highly trained in-country experts capable of assessing the relevance and relative effectiveness of new or improved fertilizers or fertilization practices.
3. Identifying constraints to the introduction of new or modified fertilizer products and practices that would increase use effectiveness of fertilizer by the economically disadvantaged farmers; providing policymakers with information on the advantage of new or modified fertilizers or fertilization practices.
4. Developing close working links with the fertilizer programs of the other international institutions including the international agricultural research centers (IARCs), as well as U.N. organizations; cooperating with these organizations in specific country activities to execute action plans.

The goal of IFDC production technology projects is to assist the developing countries in proper selection of production technology, startup, and efficient operation of production facilities. To achieve this goal, IFDC should serve as engineering advisor on a variety of projects; assist in resolving technical problems arising from modification in improvements of plant operations, raising plant capacity, improving pollution control efforts, reducing energy consumption, and plant maintenance; and develop cost estimates of establishing fertilizer plants of different capacities in different situation such as fluid or dry straight fertilizers as well as chemically or physically combined mixtures.

The goal of IFDC's fertilizer marketing program is to establish sound marketing systems in developing countries and to facilitate improvements in existing systems to ensure that the farmers receive timely deliveries of recommended fertilizer products at an attractive price. Toward the fulfillment of this goal, IFDC should (1) provide assistance in fertilizer policy development and marketing system improvement; (2) provide guidance on the status and applicability of physical and chemical mixtures (fluid and/or dry) to developing countries; (3) revitalize and expand the Center's marketing information services program; (4) assess deficiencies in marketing systems in selected developing

countries and recommend action plans for improvement; (5) develop guidelines on fertilizer marketing costs; (6) promote efficient and balanced use of NPK fertilizers; and (7) aid in the evaluation of the market potential for various products and practices.

The transfer of technology to developing countries involves the transfer of skills, and the most effective means of building the human resource capability of the developing countries is through training. Changes that are taking place in developing-country agriculture necessitate shifts in the focus and technical content of training programs to be offered.

Training—The transfer of technology to developing countries involves the transfer of skills, and the most effective means of building the human resource capability of the developing countries is through training. Changes that are taking place in developing-country agriculture necessitate shifts in the focus and technical content of training programs to be offered. Another shift taking place is the need for specific and sharply focused programs rather than general programs. Computer-based analysis and simulations, econometric models, environmental and pollution issues, and the effects of government policies of the fertilizer sector are some of the new areas that IFDC training programs should address during the next decade.

Regional Priorities

Asia—IFDC's emphasis in Asia should be to initiate policy research to (1) provide decisionmakers with information about the potential impact of alternative means of reducing subsidies; (2) continue technology transfer in fertilizer production and marketing to improve efficiencies and lower costs; (3) further adaptive research for the introduction of urea deep placement for wetland rice and move to the introduction of the practice in appropriate areas; (4) assist national scientists in delineating fertilizer nutrient requirements and economically efficient sources and fertilizer management; (5) provide technical assistance in formulating and economically producing desirable fertilizer grades; (6) initiate research on crops other than rice and wheat that are consistent with national priorities to diversify and upgrade the national diet and increase foreign exchange savings and farmers' income; and (7) identify issues and conduct research that will lead to an environmentally safe and economically sustainable agriculture.

Latin America—IFDC's research priorities in Latin America should be to (1) continue the program of identification, quantification, and determination of economic potential of phosphate rocks in the region and expand this activity to include indigenous sources of energy, potash, and micronutrients; (2) initiate nitrogen efficiency research with emphasis on rainfed rice and upland crops; (3) pursue technical assistance activities aimed at improving the efficiency of fertilizer production and marketing systems in the region; (4) initiate research on fertilizer use technologies for selected export crops; and (5) initiate analysis of fertilizer-related public policies and a study of the socioeconomic constraints to fertilizer use.

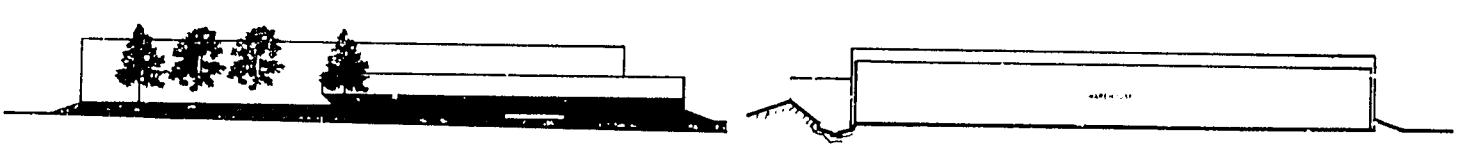
Sub-Saharan Africa—IFDC's research priorities in sub-Saharan Africa should be to (1) initiate a program of identification, quantification, determination of economic potential, and documentation of agrominerals in the region with initial emphasis on phosphate rocks; (2) initiate and continue agronomic research as a part of overall regional network for fertilizer evaluation to delineate the effects of fertilizer nutrients on local food crop production; (3) continue socioeconomic research to better identify the constraints to fertilizer adoption and assess government policy measures that would effectively remove these constraints; (4) initiate socioeconomic research to assess the role of women relative to the fertilizer sector; (5) evaluate the role and economics of various supply options in meeting the fertilizer needs of the region; (6) intensify technology transfer efforts; and (7) identify countries that have the potential to increase the use of fertilizers in significant quantities over the next decade.

The Middle East and North Africa—IFDC's emphasis in the Middle East and North Africa should be to (1) develop agronomic research programs to better identify nitrogen, phosphorus, and potassium relationships and their impact on crop production in the region; (2) conduct a comprehensive study of the fertilizer and agriculture sectors in the region; (3) identify problems hindering the development of fertilizer recommendations and their transfer; (4) assess and document in the raw material database the agrominerals indigenous to the region; and (5) identify issues and conduct research that will result in an environmentally safe and sustainable agriculture.

The most valuable product of IFDC is information, but its full impact can only be realized if it is well disseminated. While IFDC has been relatively successful in disseminating results of research, this activity should be strengthened during the next decade.

Information Dissemination

The most valuable product of IFDC is information, but its full impact can only be realized if it is well disseminated. While IFDC has been relatively successful in disseminating results of research, this activity should be strengthened during the next decade. IFDC should keep abreast of the rapid technological advances being achieved in international communications and take measures to ensure that it serves as a model to developing countries on ways to access, analyze, and disseminate information on fertilizer. In addition, more emphasis should be placed on producing technical bulletins as a means of communicating research results. As a contributor to the Compact Agricultural Research Library being developed by the Consultative Group on International Agricultural Research system, IFDC should ensure the permanent preservation, increased international awareness, and guaranteed availability of its publications in developing countires.



Organization Development

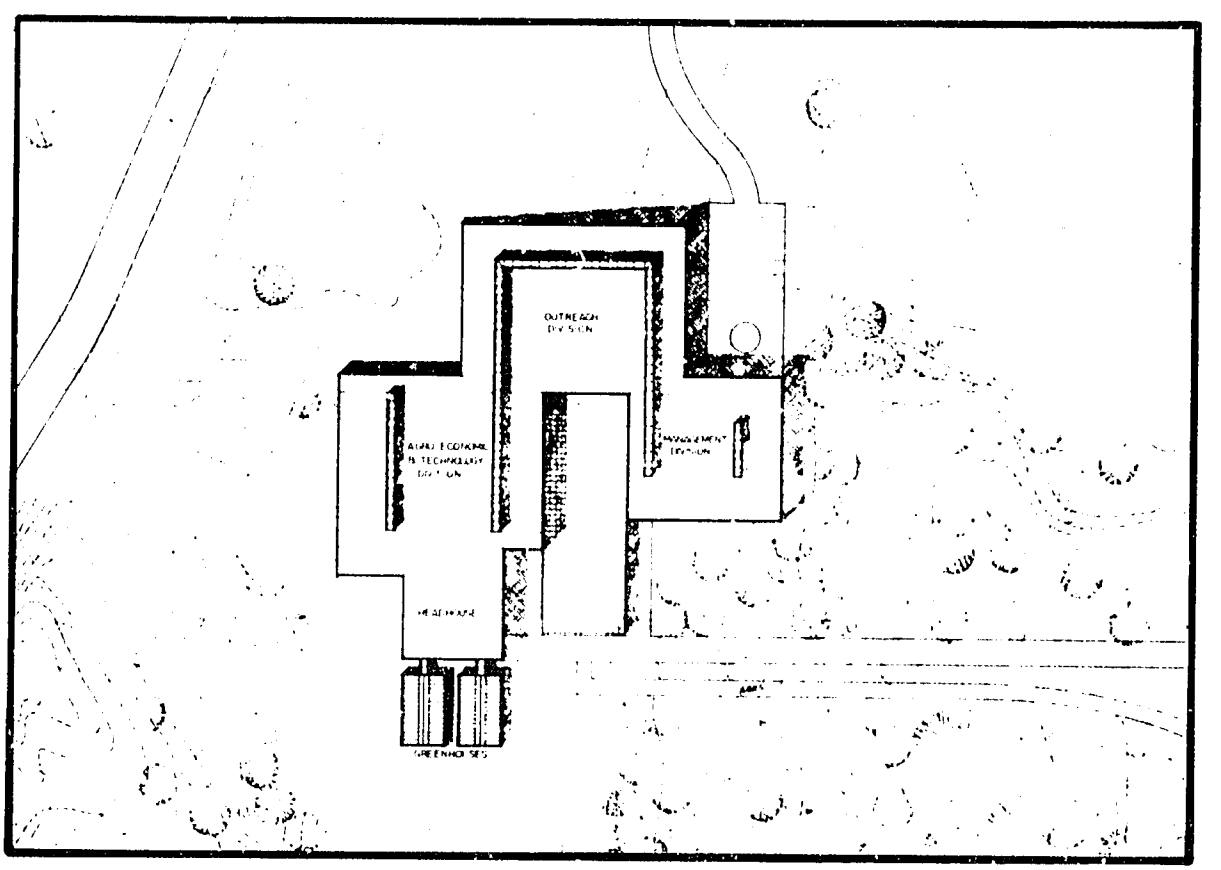
The highlight of the Report's recommendations regarding organization development was that the multidisciplinary task team approach to problem solving should be revitalized. This would facilitate the interaction of such disciplines as soil scientists, agronomists, engineers, chemists, economists, and sociologists in the total fabric of research and development activities. It would also promote the progression of an idea through research and development, evaluation, and introduction. In addition, it would foster the transfer of technology to the developing countries involving fertilizer production/use, marketing/distribution, and training.

Linkages

In the next 10 years, the existing collaboration between national institutions, other IARCs, various U.N. organizations, and IFDC should be strengthened. New ties with other institutions should be established, particularly as related to introducing and evaluating new and existing fertilizer technology and fertilization practices.

Conclusion

This Plan should be viewed as a general guide to orient the future direction of IFDC's efforts in research, technology transfer, training, and related activities. Detailed plans involving an update of this document, based on expected funding, will be prepared every 2 years. Biennial internal and quinquennial external reviews of ongoing programs are recommended to ensure that IFDC is addressing the needs of target beneficiaries in developing countries.



Impacting the African Agricultural Scene

The role of women in African agriculture is very important.

At present Africa's population is increasing at a rate of 3% per year. Approximately 75% of the people of tropical Africa live in rural areas and are dependent on agriculture for their livelihood.

Even with this strong rural orientation, agriculture in sub-Saharan Africa is not keeping pace in supplying the needs of a rapidly expanding population. Food production is increasing at a rate of only 2% per year. Therefore, this results in a decline of 1% in per capita food production. If these trends continue, tropical Africa could be producing only 75% of its food requirements by the year 2000.

The challenges facing African farmers are varied and numerous Not only must they battle against harsh environmental conditions such as drought as well as contend with diseases and insects that attack their food crops but also they must cope with infrastructural weaknesses that create uncertainties as to their ability to receive inputs on time or sell the farm's products at fair prices. Most of Africa's soils are highly weathered and leached and low in organic matter and plant nutrients. As a result, fertility is low, and erosion and desertification have accelerated. Compounding these problems is a low level of fertilizer use. Most African farmers are unaware of how fertilizer use can increase crop yields because they have little or no access to fertilizer. Tropical Africa uses only 7 kg/ha of fertilizer; Latin America uses almost 5 times as much; and Asia uses more than 11 times as much.

To help improve the fertility of the soils and, thus, to help get agriculture moving in tropical Africa, IFDC in 1987 established a regional base in Togo, West Africa. IFDC's approach in West Africa relies on a high level of cooperation and collaboration with national research programs. During 1987 eight West African countries were visited to obtain firsthand knowledge on the needs of national institutions in relation to fertilizer sector development.

The particular challenges facing African national research programs were highlighted as well as the constraints that make progress so difficult. To meet the special needs of these countries, responses in these three areas must be made:

1. Sustained research attention to food crops.

2. Training of Africans as fertilizer sector specialists to serve the national research marketing or extension activities.
3. The availability of financial resources to develop national research or extension capacities thereby allowing the development and transfer of fertilizer technologies to the overwhelming majority of resource-poor family farms.

From its West African vantage point, IFDC will conduct a range of fertilizer research, training, and technical assistance activities tailored to serve the special needs of this region. IFDC's staff in West Africa have mounted applied research and training programs involving the exploration and development of indigenous resources, efficient fertilizer use, and effective policy formulation. In addition, the West Africa Division is assisting its target countries in establishing effective lines of communication among researchers, marketing agencies, extension workers and farmers in relation to fertilizer use for crop production. This regional base serves as the hub for fertilizer-related research activities in the West African region of the sub-Sahara. Data generated through research networks will be processed, analyzed, and maintained in interactive databases accessible to national collaborators.

The training programs of the West Africa office will be an important resource in meeting the human resource requirements of the region. It is projected that for the sub-Sahara as many as 1,000 new scientific, technical, and management positions will need to be filled each year over the next 20 years. Most of these positions will deal directly with fertilizer and will apply directly to the problems facing West Africa.

Unbiased and informed technical assistance can be of tremendous value in developing the national fertilizer sectors of sub-Saharan Africa. On a cost-reimbursement basis, the staff of the West Africa Division will provide assistance to national programs and donor organizations on least-cost strategies to deliver fertilizer to the farm level. Technical services in the areas of engineering, marketing and distribution, agronomy, and fertilizer sector development will be provided to the countries of the region.

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This regional division is an integral part of the overall IFDC organization. Its training, laboratory, greenhouse, office, and pilot-plant facilities will be designed to complement the facilities available at Headquarters, which will also provide important technical and administrative support to the West Africa Division.

Accomplishing the goals of the West Africa Division will be made much easier due to the

This Togolese market scene represents the ultimate goal of IFDC's work in Africa.

Dr. Uzo Mokwunye, (right), Coordinator of Agronomic Research, IFDC-West Africa, receives some sage advice from a master agriculturalist, Dr. Norman L. Borlaug - 1970 Recipient of the Nobel Peace Prize.

existence of a wealth of agromineral resources in the region that can be used to produce fertilizers. About 20 sub-Saharan countries have phosphate deposits, 10 have natural gas, and others have potash and sulfur that can be used to produce a range of fertilizers.

As the African people chart a new course for their agriculture sectors, they realize that necessary advances will require investments in irrigation, fertilizer, improved seeds, research, training, and extension services. IFDC stands ready to assist the African people in charting this new course by supplying fertilizer and soil fertility expertise and information. Through its activities in research, technical assistance, and training, IFDC continues to impact the African agricultural scene.

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Research Activities

West African Fertilizer Management and Evaluation Network

Since the West African Fertilizer Management and Evaluation Network (WAFMEN) was established in 1982, it has expanded both in scope of work and the number of participating nations. During 1987 institutions in 14 countries (Sénégal, Gambia, Guinée, Mali, Sierra Leone, Liberia, Côte d'Ivoire, Burkina Faso, Ghana, Togo, Benin, Niger, Nigeria, and Cameroon) actively participated in the research activities of the Network. WAFMEN has indeed become a cornerstone upon which the agronomic program of the newly established IFDC-West Africa Division has been built. It has become a powerful tool allowing the coordinated testing of research concepts and specific products across the diverse agroclimatic zones of West Africa.

WAFMEN Fifth Annual Workshop

Early in 1987 the members of this network met in Lomé, Togo, to discuss the past season's results and to plan for the 1987 season. Organized jointly by the Ministry of Rural Development, Republic of Togo, and IFDC, with support from the International Development Research Centre (IDRC), the meeting brought together 42 delegates from 15 West African nations. The network continues to expand; every nation in continental West Africa from Senegal to Cameroon is now a member of the Network.

The WAFMEN Workshop deliberations focused on the extreme fragility of West African soils and the need to adapt technology developed through agricultural research to fit the needs of the African environment. The delegates recognize that only the development of these technologies and their widespread implementation will allow true progress to be achieved in the fight against underdevelopment.

After individual presentations of research results, general discussions were held among the member delegates concerning problems encountered in the past season and possible

new directions for research. Significant interest was created by research results showing a significant positive effect of organic materials including crop residue incorporation on crop response to fertilizer application. Optimal crop residue management will become critical to establishing and maintaining high fertility of the fragile soils of West Africa. Studies of its effect on long-term crop yields in coordination with fertilizer use were therefore incorporated into the trials of several programs.

Many of the soils of West Africa generally have low phosphate fixation capacity, and therefore phosphate fertilization can have a positive effect on yields for several years after the season of initial application. Thus, the economic benefit of phosphate fertilizer can spread over a number of years. This important aspect of phosphate fertilizer economy and use is being studied by most collaborators within the network. Data gained from a variety of phosphate materials including phosphate ores from West Africa will provide valuable information regarding the long-term benefits of phosphate use to the farmer.

It was decided that the nitrogen program should continue its emphasis on optimizing the efficiency of fertilizer urea. Urea dominates the market of the West African Network because of its high analysis and dominance in world trade. However, the efficiency of various forms of nitrogen, particularly urea, varies greatly depending on how and when these forms are applied to the soil as well as upon the rainfall patterns during the growing season. Network trials, some employing the isotope ^{15}N, will continue to focus on optimizing nitrogen management to obtain maximum efficiency. Data collected in these trials will be used as a basis to establish a maize/nitrogen modeling program designed to understand and predict nitrogen fertilizer response across the West Africa region.

Nitrogen Research—Experimental Station

During 1987 WAFMEN research on nitrogen continued to focus on the assessment of the primary food crops' requirements of this nutrient, the appropriate fertilizer sources to be used to meet these requirements, and the management practices that can be adopted by the farmer to improve the use efficiency of applied nitrogen fertilizers. Results from Network

The West African Fertilizer Management and Evaluation Network has become a powerful tool allowing the coordinated testing of research concepts and specific products across the diverse agroclimatic zones of West Africa.

collaborators during 1987 showed that maize on the average required 120 kg nitrogen/ha in the humid zone and 80 kg nitrogen/ha in the subhumid zone for optimum growth. At these rates, a farmer would expect a yield increase of 15 kg of grain in the humid zone and 19.3 kg of grain in the subhumid zone for each kilogram of nitrogen applied. In the drier regions, 50 kg nitrogen/ha was optimal for sorghum, and the application of this nitrogen rate would produce an increase of 20 kg of grain per kilogram of nitrogen applied (Figure 1).

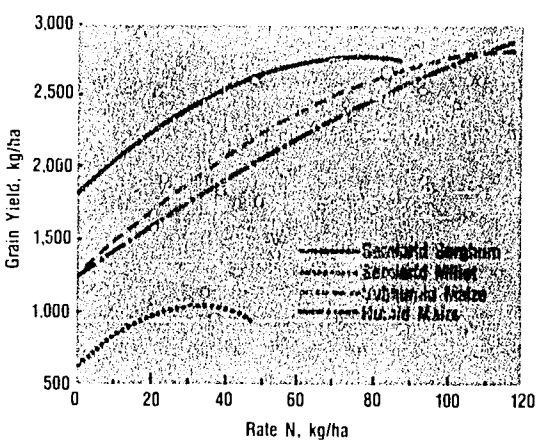

Figure 1. Average Response Functions for Nitrogen Fertilizer Measured Over Various Climatic Zones.

Results of trials from all ecological zones showed that broadcast and incorporated urea was as efficient as banding and the more labor-intensive method of point placement. However, for the most efficient use, nitrogen must be split-applied, regardless of the method of application. Previous trials on sandy soils of Niger have shown that substantial losses occur when urea is point placed. During 1987 a trial comparing the performance of point-placed calcium ammonium nitrate (CAN), ammonium sulfate, and urea showed a superior performance for point-placed CAN.

A Togolese farmer harvests rice. Many of Africa's farming operations are carried out by women.

Phosphate Research—Experimental Station

Use of conventional, water-soluble phosphate fertilizers such as single superphosphate (SSP) and triple superphosphate (TSP) by the subsistence farmers in sub-Saharan Africa has been limited primarily due to the high cost of these fertilizers. The primary goal of IFDC's phosphate research in sub-Saharan Africa has been to find the most cost-effective ways to use the phosphate rocks that are indigenous to the region. Direct application of indigenous, finely ground phosphate rock has been tested and used on some tropical soils because of lower capital investment and production cost. However, direct application of phosphate rock with low reactivity does not always give satisfactory results, especially if used for short-term crops, e.g., maize, beans, and potatoes. Partial acidulation of phosphate rock represents an alternative means of using indigenous resources that can approach or equal the agronomic effectiveness of TSP and SSP in certain tropical soils and crops. Agronomic trials are being conducted in 14 countries of the sub-Saharan region to compare the performance of the more promising finely ground phosphate rocks such as Tahoua phosphate rock (Niger) and Tilemsi Valley phosphate rock (Mali) and the partially acidulated forms of the less reactive phosphate rocks such as Togo phosphate rock, Kodjari phosphate rock (Burkina Faso), and Parc W phosphate rock (Niger) with the superphosphates.

The primary goal of IFDC's phosphate research in sub-Saharan Africa has been to find the most cost-effective ways to use the phosphate rocks that are indigenous to the region.

During 1987 long-term trials established since 1982 continued to provide valuable information on the residual effects of different phosphate fertilizers. For example, data shown in Table 1 from the work in Niger indicate that additions of small doses of phosphate fertilizer, including phosphate rock, can result in a gradual buildup of the phosphorus fertility of the soils. One way to take advantage of the good residual effectiveness of phosphate fertilizers in these soils is to devise a cropping system that would require a single application of phosphate fertilizers for a number of crops or for a given rotation. In 1984 different rates of phosphate fertilizers were applied to a field at Gobery in Niger and subsequently cropped for 4 years. In 1987 the yield from the application of 90 kg P_2O_5/ha as SSP was still four times higher than the control treatment.

Table 1.
Available Phosphorus (ppm Bray P1) in Gobery Soil After Annual Fertilizer Additions Followed by Cropping to Millet

Source/Application Rate	Available Phosphorus	
	90 kg P_2O_5/ha	160 kg P_2O_5/ha
	(ppm)	
Parc W phosphate rock	3.33	4.57
50% Parc W PAPR	4.62	8.05
SSP	5.64	11.11
TSP	5.29	10.28
Control	2.24	2.24

In the Ultisols results of trials conducted in Sierra Leone, Nigeria, and Cameroon showed that maize responded significantly to both SSP and 50% partially acidulated Togo phosphate rock with SSP being superior to PAPR. Soil acidity was identified as a major problem limiting yields in the Ultisols. The relative agronomic effectiveness (RAE) of 50% Togo PAPR compared to SSP in trials at Sierra Leone and Nigeria was 66% and 67%, respectively.

Results of trials conducted in Oxisols and Alfisols showed that maize and sorghum

responded positively to additions of PAPR made from such unreactive rocks as the Togo phosphate rock and Kodjari phosphate rock. Figure 2 illustrates the performance of 50% partially acidulated Togo phosphate rock at Amoutchou in Togo. Similar strong performances were shown by 50% partially acidulated Kodjari phosphate rock with maize (RAE = 90%) and with sorghum (RAE = 74%) in Burkina Faso.

Recent field trials conducted in Niger and Gambia, however, showed that PAPR prepared from phosphate rocks containing high levels of *aluminum oxide and iron oxide* was not as effective as SSP and TSP and sometimes was even less effective than the finely ground phosphate rocks (Figure 3). These phosphate rocks were identified as Kodjari rock from Burkina Faso, Tilemsi Valley rock from Mali, and Tahoua rock from Niger.

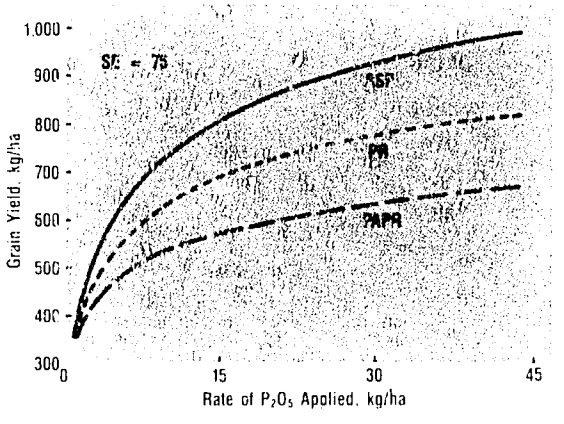

Figure 3. Grain Yield of Maize Obtained With SSP, Finely Ground Tahoua Phosphate Rock, and Granular Tahoua PAPR-50 (Sulfuric Acid) at Gobery, Niger.

To understand more about the detrimental effect of aluminum and iron oxide content on the agronomic effectiveness of PAPR, IFDC's soil scientists and chemical engineers at Headquarters launched a comprehensive study in 1987 using several phosphate rocks from West Africa. During the investigation, the IFDC-developed single-step PAPR process was modified by adding a cooler, whereby ambient air was used to cool the hot PAPR materials coming out of the dryer. It was found that this modification which provided an immediate cooling effect reduced the reversion of water-soluble phosphorus to water-insoluble phosphorus during aging for those PAPR products prepared from rocks with high contents of

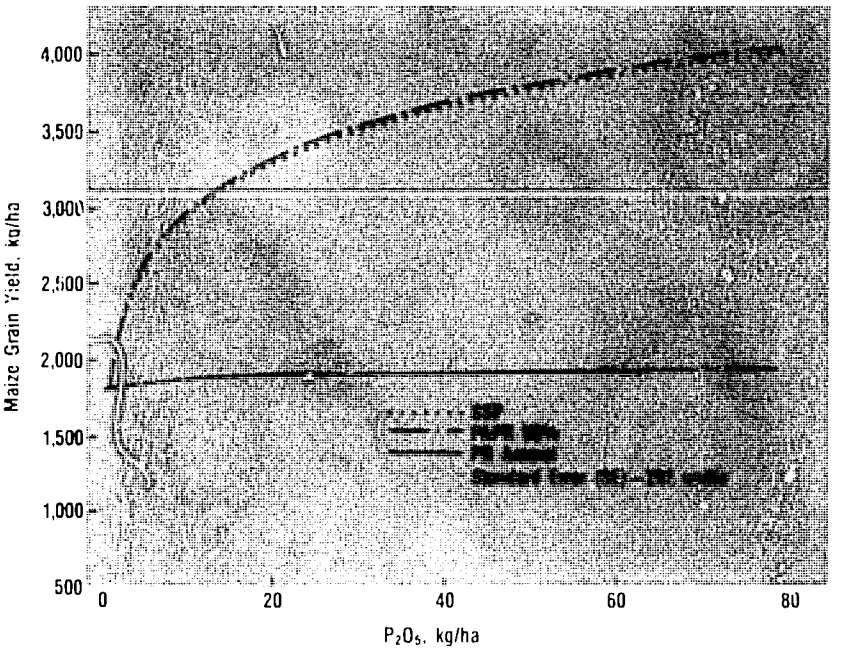

Figure 2. Effect of Phosphorus Fertilizers on Yield of Maize at Amoutchou, Togo (1987).

aluminum and iron oxide. However, even with the cooling process, it was found that water solubilities of the PAPR products made from phosphate rocks with high contents of aluminum and iron oxide were lower than those with low contents of these elements. The effect was more pronounced at 50% acidulation than at 30% acidulation; presumably the presence of sulfuric acid caused more aluminum and iron oxide to react with water-soluble phosphorus to form water-insoluble phosphorus such as aluminum phosphates and iron phosphates. Because of the reduction in water-soluble phosphorus and total available phosphorus, the relative agronomic effectiveness of PAPR with respect to SSP was found to decrease with increasing aluminum and iron content in phosphate rock. The results were consistent with the poor performance of PAPR products prepared from phosphate rocks with high contents of aluminum and iron oxide as observed under field conditions in West Africa. Thus, phosphate rocks having high contents of aluminum and iron oxide may not be suitable for PAPR production. Alternatively, compacting the phosphate rocks having high contents of these elements with TSP can produce effective PAPR-equivalent products with good physical and chemical quality.

A Benin farmer plants maize as part of IFDC's On-Farm Research Program in West Africa.

On-Farm Research

The ultimate goal of WAFMEN is to promote the development of national programs on fertilizer research and extension. Information generated for a generalized soil unit or agroecological zone through on-station research must be adapted to local conditions through on-farm evaluation of the package. IFDC scientists are developing technologies for on-farm testing of fertilizers. Network members would then be encouraged to adapt these technologies to their specific conditions.

By 1986 it was felt that the WAFMEN research in Niger had developed a fertilizer package that could be evaluated under farmer-operating conditions. This testing was initiated during 1986 in the village of Gobery and was continued during 1987.

The primary objective of the tests was to evaluate a fertilizer package when used by the typical subsistence farmer. Additional objectives were:

The ultimate goal of WAFMEN is to promote the development of national programs on fertilizer research and extension. Information generated for a generalized soil unit or agroecological zone through on-station research must be adapted to local conditions through on-farm evaluation of the package. IFDC scientists are developing technologies for on-farm testing of fertilizers.

1. To study the relative efficiency of Parc W PAPR compared with SSP.
2. To study the effect of placement methods on response by millet to phosphate fertilizers.
3. To ascertain if the use of urea as a nitrogen source would economically enhance the efficiency of phosphate use by millet.

A group of 19 farmers has been involved in the trial; each farmer used four of the treatments listed in Table 2. Fertilizers were given to the farmers, and they were allowed to plant, fertilize, weed, and harvest when they saw fit.

Table 2.
Treatments in Farmers' Tests—Treatments 3, 4, and 5 Were Common to all Farmers, 1986.

	Phosphate			Nitrogen	
Treatment	P Source	P_2O_5 Rate (kg P_2O_5/ha)	Application Method	N Rate (kg N/ha)	Application Method
1	PAPR	30	Broadcast Incorporated	30	Broadcast Incorporated
2	SSP	30	Broadcast Incorporated	30	Broadcast Incorporated
3	SSP	30	Broadcast Incorporated	None	
4	SSP	30	Point placed	30	Point placed
5	Control	-	-	-	-

Since the farmers of Gobery generally did not have access to plows, fertilizers could not be deeply incorporated into the soil but were worked in lightly with a hoe at weeding. This was expected to limit phosphate availability as most of the phosphate would remain in the drier surface horizons. For this reason, hill placement of phosphate was suggested as one alternative treatment. A shallow hole was to be dug near the plant (8-10 cm) with a stick or hoe at the time of planting and the phosphate applied as a point treatment into the moist subsoil. Previous field studies have shown that urea-nitrogen is very susceptible to losses via volatilization. However, laboratory studies at IFDC showed a 27% reduction in volatilization when urea was mixed with SSP and point-placed. This was attributed to the acidity of the SSP, which reduced the fertilizer-zone pH, thereby reducing nitrogen losses. Thus, both urea and SSP were to be mixed together and point placed at planting. This

treatment was compared with broadcast SSP or PAPR plus or minus supplementary urea-nitrogen.

Though no significant difference was noted between fertilizer treatments, fertilizer use increased yields of millet averaging 250% over those of controls. When the SSP plus nitrogen and SSP minus nitrogen treatments were compared, it was evident that the use of urea-nitrogen under farmers' conditions improved yields only a slight (18%) but insignificant amount. CAN might have been more efficient than urea in this regard because it has been shown to be more efficiently used by the plant. This product, however, is not as easily obtained as urea in Niger. Previous studies have shown that the nitrogen requirement of millet is highly correlated with total rainfall received. The rainfall amounts of 1986 and 1987 were very close to the average expected for the Gobery region indicating that, in an average year, the use of urea would probably not be an economically viable practice. Crop density did not significantly affect nitrogen use efficiency. No significant effect of point placement of phosphate and nitrogen was found.

The comparison of SSP and PAPR showed that both performed equally indicating that PAPR from the local Parc W phosphate rock may be substituted for commercially available phosphate sources without expectation of any yield reduction in a normal farm situation.

Low planting density is generally associated with risk aversion; the farmers equate low plant population with lowered water use. Although the nationally recommended plant density is 30,000 plants/ha, most farmers employed much lower densities in these experiments ranging from 2,400 to 37,500 plants/ha (average 13,800 plants/ha). This density factor was shown to have a strong effect on the yields obtained by the farmer as well as the response of millet to fertilizer. In the absence of fertilizer, control yields were generally unaffected by density except at a very low plant population of less than 7,500 plants/ha (Table 3). However, the yields obtained with fertilizer application were greatly improved as cropping density was increased. Thus, the benefit of fertilizer application increased in a like manner such that a farmer employing high-density planting would have received twice the benefit from his fertilizer input as would someone using a lower plant population.

To promote the sustainability of soil fertility, it is also critical to understand the long-term fertility requirements of soil-crop systems. Long-term soil fertility studies involving use of fertilizers, lime, crop residues, manures, secondary and micronutrients have been initiated in the primary agroecological zones of West Africa.

Table 3.
Millet Yield and Crop Response in Farmer's Trials as Affected by Cropping Density and Fertilizer Use, Gobery, Niger, 1986/87

Density (plants/ha)	(1) Yield Control (kg/ha)	(2) Average Yield Fertilizer Plots (kg/ha)	Yield Benefit to Fertilizer Use (2-1) (kg/ha)
>8,000	326	1,257	931
6,000-8,000	426	1,044	618
4,000-6,000	433	912	480
2,500-4,000	252	587	335
<2,500	97	493	396

During a normal growing season in Niger, frequent dry periods can occur causing severe moisture stress that could kill the less hardy plants. It is important therefore to note the strong effect of fertilizer use on plant survival over a complete growing season. Although each farmer had planted all four of his treatments at the same plant density, it was found that the average density at harvest was almost 50% higher in the plots that had received fertilizer than in the controls (average of 15,120 plants versus 10,170 plants/ha, respectively). It is speculated that the fertilizers had helped the young plants become quickly and vigorously established thereby helping them survive the rigors of the climate of Niger.

This study has shown that the farmer could benefit greatly from the use of fertilizer. However, it also indicates that farm management, particularly choice of plant density, can have a very significant effect on fertilizer use efficiency and benefits derived from the use of fertilizers.

To promote the sustainability of soil fertility, it is also critical to understand the long-term fertility requirements of soil-crop systems. Long-term soil fertility studies involving use of fertilizers, lime, crop residues, manures, secondary and micronutrients have been initiated in the primary agroecological zones of West Africa.

During 1987 the Sulfur Program continued to participate in WAFMEN. A total of eight experiments were carried out at six sites in Niger, Burkina Faso, and Togo.

The results of the first year of a long-term trial showed that in the humid and subhumid zones of Togo, nitrogen and phosphorus were the key nutrients required by the crops. Use of 10 tonnes of manure per hectare fared little better than the control treatment. These results are in contrast with a similar experiment conducted earlier on the very sandy soils of Niger, at Sadore which showed that 10 tonnes of manure/ha outyielded the NPK treatment by 25%. Also in this ecosystem, the use of crop residues alone at the rate of 2 tonnes/ha was 82% as productive as the use of an NPK fertilizer.

Sulfur Research

Experimental Station

During 1987 the Sulfur Program continued to participate in WAFMEN. A total of eight experiments were carried out at six sites in Niger, Burkina Faso, and Togo. Six of these trials are on-going sulfur experiments designed to study the relative efficiency and residual value of sulfate and elemental sulfur sources for cereals (millet, sorghum, and maize) in a range of agroclimatic conditions. Two of the trials (one in Niger and one in Togo) actually comprised sulfur treatments incorporated into existing phosphate trials for the purpose of examining the effect of phosphate fertilizer on sulfur fertilizer movement in the soil profile. These latter experiments as well as three of the sulfur fertilizer source experiments utilize ^{35}S-labeled materials to help quantify sulfur fertilizer recovery by crops and its fate in the soil.

The three sulfur fertilizer source trials in Niger were adversely affected by drought in 1987 and did not respond to fertilizers. The remaining trials with maize in Burkina Faso and Togo gave maximum responses to sulfur fertilizers ranging from 32% to 62% (Table 4).

Table 4.
Maximum Grain Yield Responses to Sulfur Fertilizers in West Africa (1987 Season)

Sulfur Source	Farako-ba Burkina Faso (kg/ha)	Sarakawa Togo (kg/ha)	Amoutchou Togo (kg/ha)
Control	2,478	1,426	1,461
Sulfatic	3,528	2,215	2,055
Elemental	3,259	2,309	2,310

Figure 4 illustrates maize grain responses in 1985, 1986, and 1987 to sulfur from elemental sulfur and phosphogypsum applied to an experiment in Togo in 1985. The initial superior response to gypsum in 1985 has given way to a more sustained response from residual elemental sulfur in subsequent years. In another experiment in Togo, established in 1987, linear responses by maize to sulfur were obtained from elemental sulfur cogranulated TSP (SGTSP) and single superphosphate (SSP) up to the highest sulfur rate applied (40 kg/ha, Figure 5.) Here, the granulated elemental sulfur source was marginally superior to the sulfate source from the onset.

The poorer residual performance of sulfate sources is probably explained by the strong susceptibility to leaching in the coarse-textured soils such as those found in much of West Africa. The soil profile distribution of ^{35}S from sulfate fertilizer sources in experiments conducted in Niger and Togo confirms a considerable downward mobility of sulfate in these soils. In contrast, considerably less sulfate was derived from elemental sulfur sources and was found almost entirely within 30 cm of the soil surface.

Since phosphate competes strongly with sulfate for the same adsorption sites on soil colloids, application of phosphate fertilizer may enhance leaching losses of sulfur from sulfate. Experiments were conducted to examine the effect of phosphate levels (either contrasting current rates or contrasting histories of phosphate application) on sulfate leaching in two rainfall environments. Sulfate from SSP incorporated to 10-cm depth in Niger (640 mm rainfall) had moved well into the soil profile by harvest; however, the depth and amount of sulfate moved were not significantly affected by phosphate fertilizer rate. In Togo (1,500 mm rainfall), the distribution of fertilizer-derived sulfate in the soil profile was not affected by the higher phosphate status of treatments

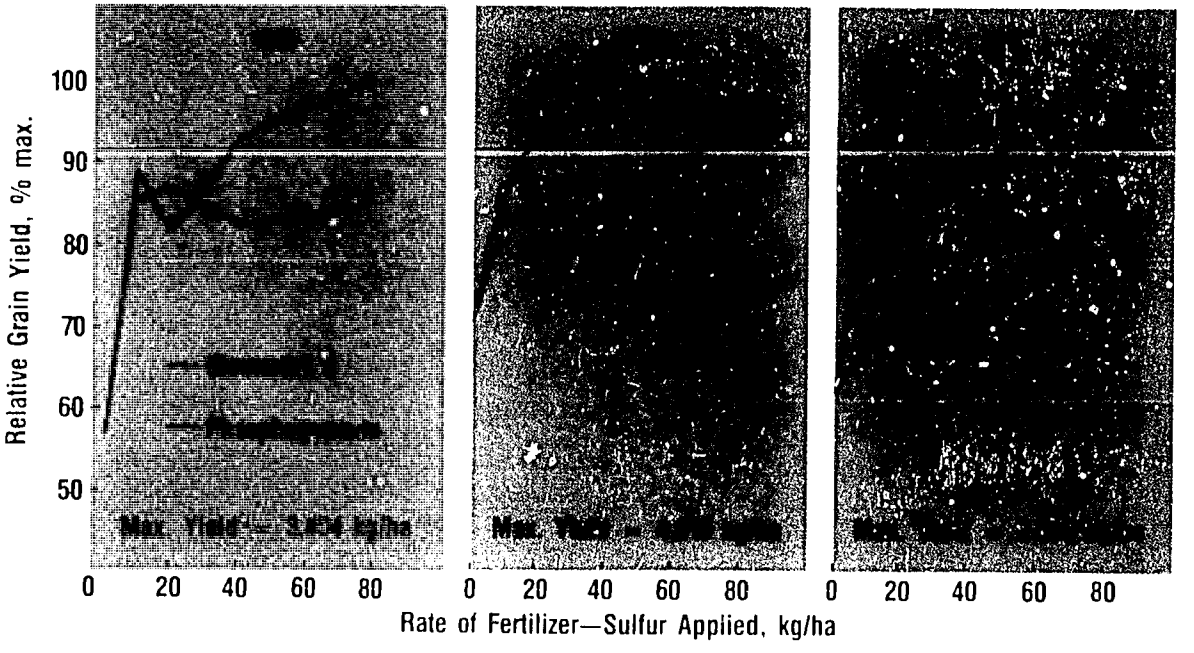

Figure 4. Maize Grain Responses to Sulfur From Elemental Sulfur and Phosphogypsum (Togo, 1985-87).

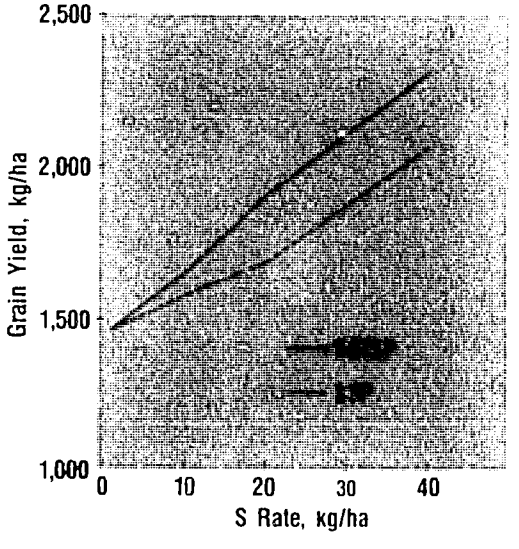

Figure 5. Maize Response to Sulfur From Elemental Sulfur Cogranulated TSP and SSP (Togo, 1987).

receiving 80 kg P_2O_5/ha annually in contrast to those receiving 80 kg P_2O_5/ha once only in 1983. These preliminary results suggest that phosphate applied at optimal rates has little effect on sulfate leaching under field conditions.

Fertilizer sulfur recovery in plant top growth was estimated in two ^{35}S experiments conducted in Niger in 1986. In one trial total top growth of sorghum responded equally well to sulfur from SSP and SGTSP although recovery of fertilizer sulfur was approximately 25% from SSP and 9% from SGTSP, despite greater leaching of SSP into the soil profile. It seems that spatial availability of SSP was increased. In another experiment in a drier environment, recovery by millet tops of sulfur from SSP was only 6% of that applied. These data, together with a similar observation of sulfur recovered from gypsum in a 1985 trial with millet, indicate poor recovery of fertilizer sulfur by crops grown in this region. Questions which must be addressed in future experiments include:

a. Are fertilizer sulfur recoveries similarly low at lower rates of sulfur application?
b. To what degree is residual fertilizer sulfur recovered by subsequent crops?
c. How can sulfur recovery be improved?

Incorporation of elemental sulfur into fertilizer such as urea, TSP, or DAP is a possible means of supplying a crop's sulfur requirements in a high-analysis product as well as a convenient method of applying the relatively low rates of sulfur usually required from an otherwise highly concentrated source.

Oxidation of Elemental Sulfur in Multinutrient Fertilizers—Headquarters Research

Incorporation of elemental sulfur into fertilizers such as urea, TSP, or diammonium phosphate (DAP) is a possible means of supplying a crop's sulfur requirements in a high-analysis product as well as a convenient method of applying the relatively low rates of sulfur usually required from an otherwise highly concentrated (straight-grade elemental) source. Elemental sulfur, however, must be oxidized to sulfate to be absorbed by plant roots. During 1986 and 1987 we examined factors affecting the rate of oxidation of elemental sulfur in multinutrient fertilizers. Headquarters greenhouse experiments were conducted in which elemental sulfur was applied separately from or in combination with nitrogen and phosphate sources. It was observed that oxidation was enhanced when sulfur was applied in combination with nitrogen or, especially, phosphate fertilizer.

Oxidation of elemental sulfur may also be affected by the degree of dispersion of fine sulfur particles in the soil. At a given sulfur rate, the degree of dispersion is inversely related to the granule size of sulfur-containing multinutrient fertilizer. An experiment was therefore conducted to examine the effect of granule size of SGTSP on sulfur oxidation. SGTSP (16.2% elemental sulfur), screened to four granule size fractions, and SSP, both labeled with ^{35}S, were applied at four rates of sulfur to a fine sandy loam soil and cropped with wheat that was allowed to grow to maturity. Both yields and fertilizer sulfur uptake were strongly dependent on granule size. Onsize (-6 +9 Tyler mesh) SGTSP was much less effective than SSP of similar granule size despite the finely divided state of sulfur in the SGTSP granule. This result contrasts sharply with field results with maize and sorghum in West Africa where SGTSP and SSP have produced similar yield responses at the rates of sulfur applied (see above). A possible explanation may be the longer duration of the crop and the higher soil temperatures under tropical field conditions, which may have enhanced sulfur oxidation and SGTSP efficiency.

Effect of Phosphate Fertilizer Placement and Sulfur-Form on Sulfur Leaching—Headquarters Research

To further assess the significance of sulfur leaching losses associated with phosphate applications, a Headquarters greenhouse lysimeter experiment was conducted in which recovery and leaching losses of sulfur from soil and (^{35}S labeled) sulfur fertilizer were compared from different sources (SSP and SGTSP) applied using different methods (broadcast-incorporated and banded). Preliminary analysis of the data indicates that the total amount of (soil) sulfate leached is similar whether TSP is incorporated or banded. This result supports the field observations in West Africa that phosphate fertilizer at practical rates of application do not enhance sulfate leaching losses. Considerably more sulfate was leached from SSP applications, presumably sulfate originating from the SSP. However, the amount leached was reduced when SSP was banded, suggesting that banding reduces the rate of sulfate dissolution from SSP rather than its adsorption onto soil colloids. As observed in field experiments, leaching of sulfate derived from incorporated SGTSP was negligible in comparison to SSP.

Economics Research

Evaluation of Fertilizer Products and Practices

Results of field experiments conducted in 1985 and 1986 were used to study the economic potential of alternative fertilizer products and methods of application to supply nitrogen and phosphorus to maize in Nigeria and Togo and to millet and sorghum in Niger. Fertilizer response function estimates and current crop and fertilizer prices were used to calculate the fertilizer rates that maximize profits and the associated added returns, costs, and value:cost ratios for each fertilizer use technology. To evaluate phosphate fertilizers the analysis was expanded to include the benefits of residual effects of these fertilizers on crop yields in the second and, in some cases, the third crop period after the fertilizer application.

Nitrogen Fertilizers—Urea, ammonium sulfate, CAN, and urea supergranules (USG) were evaluated as alternative sources of nitrogen. Because of the important influence of climatic

factors on the agronomic effectiveness of nitrogen fertilizers, this analysis was based on response function estimates representative of the humid, subhumid, and semiarid regions.

Estimates of added returns, costs, and value:cost ratios obtained to evaluate nitrogen fertilizers and methods of application for maize in the humid and subhumid regions and for millet and sorghum in the semiarid region indicate the following:

1. Split application of nitrogen fertilizer was the most cost-effective application method.
2. For maize in the humid region, the application of urea banded at a rate of 120 kg nitrogen/ha was the most profitable (highest added returns) alternative to apply nitrogen to this crop. Another less profitable alternative was the use of USG at a rate of 110 kg nitrogen/ha.
3. For maize in the subhumid region, CAN banded, 15-15-15, and urea banded applied at rates of 120 kg nitrogen/ha were, in that order, the more profitable technologies.
4. For millet in the semiarid region, results showed that the deep placement of CAN at a rate of 132 kg/ha (34 kg of nitrogen) was the most profitable way to apply nitrogen to this crop. The deep placement of about 120 kg/ha of ammonium sulfate and the broadcasting of 110 kg/ha of CAN or 140 kg/ha of ammonium sulfate were the other three more profitable alternatives in this region. Results showed that the broadcasting of urea or CAN and the deep placement of USG had very similar levels of net added returns.
5. For sorghum in the semiarid region, the application of CAN banded at a rate of 50 kg N/ha was the most profitable technology. Urea and USG were significantly less profitable than CAN.

Phosphate Fertilizers—Ground phosphate rock, PAPR products, SSP, and TSP were evaluated as alternative sources of phosphorus to maize in locations of the humid and subhumid regions and to millet in locations of the semiarid region. These fertilizers were evaluated as a means of applying phosphorus in each crop period, i.e., in terms of their benefits in the crop period in which they were applied (initial effects) and also by including the benefits associated with their residual effects. In order to account for the time opportunity-cost of money, added returns of residual effects were discounted at a rate of 30%/year.

a. Results on Maize

The results of this evaluation can be summarized as follows:

1. **Sierra Leone**—SSP and Togo PAPR50 (% acidulation) were the most profitable sources of phosphorus. The profitability of Togo ground phosphate rock is enhanced by the benefits of residual effects. Higher value:cost ratios resulting from the residual effects of ground phosphate rock on crop yields and by its lower cost indicate a better hedge against risk.
2. **Togo**—Togo PAPR50, SSP, and TSP were the most profitable sources of phosphorus. Togo ground phosphate rock was not as profitable but yielded the highest value:cost ratios when the benefits of residual effects were included.
3. **Gambia**—The most profitable sources of phosphorus were TSP and SSP. However, when the benefits of residual effects are included, ground phosphate rock was 75% as profitable as TSP and had a higher value:cost ratio.
4. **Nigeria**—Fertilizers were evaluated only in terms of the benefits of initial effects. SSP and Togo PAPR50 were the most profitable sources of phosphorus while Togo ground phosphate rock was 70% as profitable as SSP.

These results indicate that phosphate fertilization for maize in these countries should be based on the use of ground phosphate rock and either PAPR50, SSP, or TSP.

b. Results on Millet

Results of the evaluation of phosphate fertilizers on millet at Gobery and Sadore in Niger may be summarized as follows:

1. **At Gobery**—TSP, SSP, Parc-W PAPR50, and Tahoua ground phosphate rock were in that order the more profitable sources of phosphorus. Tahoua ground phosphate rock was 97% and 92% as profitable as TSP in 1985 and 1986, respectively, and had the highest value:cost ratios. The relative profitabilities of Parc-W ground phosphate rock and PAPR50 with respect to TSP were improved by the benefits of residual effects.
2. **At Sadore**—SSP plus nitrogen, TSP, Parc-W ground phosphate rock, and

PAPR50 were the more profitable alternatives. The profitability of SSP was significantly increased as a result of the nitrogen added. The evaluation conducted by including the benefits of residual effects showed that Parc-W ground phosphate rock was as profitable as PAPR50, more profitable than SSP, and 80% as profitable as TSP.

Given the risks in crop production due to uncertain climatic factors in the semiarid region of West Africa, the results presented above provide support to the development of government programs that promote the direct application of ground phosphate rock using indigenous resources of phosphate rock.

Socioeconomic Constraints to Fertilizer Use in Western Niger

IFDC extended farm-level socioeconomic research to West Africa during 1987 when an IFDC economist and a rural sociologist conducted a study of farm-level constraints to fertilizer use in Western Niger. This project allowed IFDC to initiate this type of research in a region where farm-level socioeconomic research is needed to improve the relevance of agronomic research and the implementation of policies to facilitate the adoption of fertilizers and other agricultural production technologies.

The project represented an important experience in the study of farm-level constraints to fertilizer use in the physical and socioeconomic environment that is characteristic of an African country, as well as a contribution to IFDC's overall research efforts.

Data were collected from a sample of 48 farmers in Western Niger. The study identified constraints to fertilizer use through a comparison of the socioeconomic characteristics of users and nonusers of fertilizer. The principal constraints to fertilizer use identified in the study are (1) the serious limitations that farmers have for transporting fertilizers to the fields and products to the markets, as a result of the distances from households to fields and markets and inadequate farm-level transportation; (2) the lack of knowledge and training about the use of fertilizers; and (3) the severely limited agricultural credit and the availability of family labor. The data from the study also demonstrate that the traditional practice of organic manuring is not abandoned when commercial fertilizer is used.

This project has provided benchmark data that will be used for reference in future socioeconomic research on farm-level constraints to fertilizer use in Africa.

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East and Southeast Africa Fertilizer Research Program

The East and Southeast Africa Fertilizer Research Program, funded by the United Nations Development Programme (UNDP) and the World Bank, was initiated during 1987. An IFDC soil scientist was stationed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)/Bulawayo Station in Zimbabwe. The objective of this program is to find ways to use the indigenous resources of East and Southeast Africa in the manufacture of fertilizers needed to increase food production in that region. The soil scientist will be responsible for conducting agronomic trials using these fertilizers.

Workshops to Transfer Technology

In order for appropriate technology to be transferred to the parties who need to use it, vehicles must be developed through which this know-how can be transferred to increase food production in sub-Saharan Africa. Communication must be improved among researchers, marketing agencies, extension workers, and farmers regarding fertilizer use for crop

production. To achieve this goal, the East and Southeast Africa Fertilizer Research Program conducted two workshops during 1987.

Workshop on East and Southeast African Fertilizer Minerals

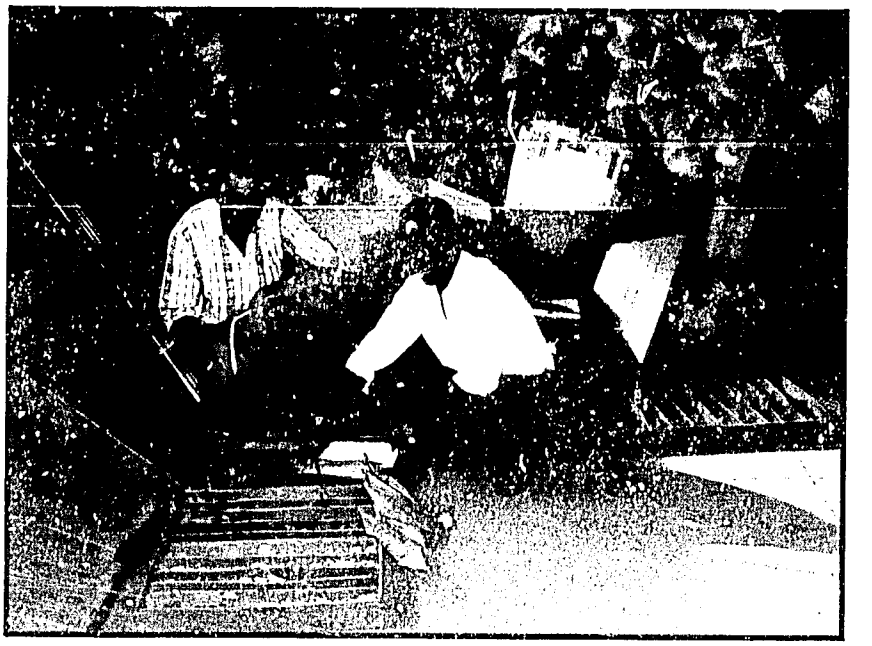
As a result of a workshop held in Lusaka, Zambia, during 1987, a geology network was established to study agromineral deposits in the region. The purpose of this network is to ascertain the potential for local raw materials to complement or replace imported fertilizers and increase food production while saving foreign exchange.

Sixteen geologists from the 11 countries of East and Southeast Africa participated in the workshop conducted by IFDC. Besides the sixteen geologists participating, nine observers from UNDP, the U.S. Agency for International Development (USAID), the Zambia Industrial and Mining Corporation, Ltd. (ZIMCO), the Zambia Geological Survey, Preferential Trade Association, Federal Republic of Germany, and the Beira Chemical Group, Ltd., of Zimbabwe attended the workshop.

This workshop was funded by the World Bank and UNDP. The activity was cohosted by ZIMCO, the Zambia Ministry of Mines (Geology Department), and the University of Zambia School of Mines.

The objective of the workshop was to establish a regional network of geological scientists and institutions in the East and Southeast African region that will (1) identify and document the occurrence of indigenous materials, (2) identify indigenous resources that can be used where appropriate to complement and replace existing supplies of imported fertilizers, and (3) identify special geological skills required to find and use indigenous resources to increase food security in the region.

Some of the workshop topics included: (1) use of indigenous agrominerals for fertilizer production, (2) overview and potential for development of phosphate deposits in east and southeast Africa, (3) nonmetallic minerals in Zambia, (4) geology survey work in Zambia, and (5) exploration of phosphate deposits in Zambia. In addition, participants in the workshop presented country reports on the geological situation in their respective countries. Reports were given on the following countries: Burundi, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Somalia, Tanzania, Uganda, Zambia, and Zimbabwe.



Steven J. Van Kauwenbergh, IFDC Mineralogist/Petrographer, and Tharcisse Songore, Geologist, Department of Mines and Geology, Government of Burundi, inspect samples of Matongo phosphate rock.

A practical viewpoint was gained through field tours to ZIMCO laboratories and beneficiation facilities of the University of Zambia School of Mines.

Workshop on Agronomic Evaluation for East and Southeast Africa

A workshop on agronomic evaluation for East and Southeast Africa, held in Nairobi, Kenya, provided an excellent forum for creating a common understanding of objectives of the East and Southeast Africa Fertilizer Research Program. Seventeen representatives from eight East and Southeast African countries participated in the

Participants in the Workshop on East and Southeast African Fertilizer Minerals examine ore samples.

As a result of a workshop held in Lusaka, Zambia, during 1987, a geology network was established to study agromineral deposits in the region. The purpose of this network is to ascertain the potential for local raw materials to complement or replace imported fertilizers and increase food production while saving foreign exchange.

workshop, sponsored by the World Bank and UNDP. The group was apprised of IFDC's role in tropical Africa and how the East and Southeast African program complements the Center's overall objectives.

Workshop attendees agreed that research programs must be created in individual countries and solutions to stated problems identified within the countries themselves. The order of priorities to be assigned to individual projects included: (1) development of indigenous fertilizer materials, (2) agronomic evaluation of possible fertilizer materials, (3) fertilizer marketing, and (4) training.

Another highlight of the Workshop was the presentation of the country reports by the delegates. These reports included statements of ongoing fertilizer research programs and the constraints for implementation. Some interesting facts were cited regarding population pressures, inadequate funding and facilities, staff requirements, and priorities. The reports generally identified areas where additional agricultural research is needed.

During the Workshop the phosphate deposits of East and Southeast Africa were discussed. Plans were made for field work, sample collection, and documentation of known deposits of all fertilizer raw materials in the region.

Potential research programs involving phosphate rock and PAPR for selected crops were discussed in depth. The size of plots, fertilizer rates, time of application, site location, crop selection, and all trial details were discussed.

Collaborators were identified in those countries represented at the Workshop to form a network on agronomic evaluation for East and Southeast Africa. The Network representatives learned that it was their responsibility to develop programs for their individual countries. IFDC's role is to assist with the country programs.

Technical Assistance

Egypt Research and Development Center

Under the sponsorship of UNDP, IFDC initiated a project covering a 4-year period to assist the Government of the Arab Republic of Egypt in establishing an Egyptian Fertilizer Development Centre (EFDC). An IFDC engineer spent 4 weeks in-country surveying the site and existing physical facilities for EFDC. He worked with representatives of the Egyptian Chemical Industries Corporation (CIC) and UNDP. During this initial phase a plan was developed covering the project's scope and objectives, budget, and activities, which were approved by CIC and UNDP (Cairo). The project's elements consist of a demonstration-scale (about 1 tph), general-purpose NPK fertilizer granulation pilot plant, a nitrogen research laboratory, a phosphate research laboratory, a physical quality evaluation laboratory, a greenhouse, training of selected EFDC personnel, and improvements to the existing library and training center.

Subsequent to this mission, another IFDC engineer made an onsite visit in preparation for development of equipment specifications and a bid document for procurement. Once approved by UNDP, IFDC expects to be involved in the project throughout the 4-year period on an as-requested basis through the United Nations Industrial Development Organization (UNIDO), the implementing agency.

Togo

The company, Office Togolais des Phosphates (OTP), has sponsored several projects at IFDC Headquarters as they evaluate ways to improve and diversify their operation for mining and exporting phosphate concentrate.

Beneficiation Pilot Plant

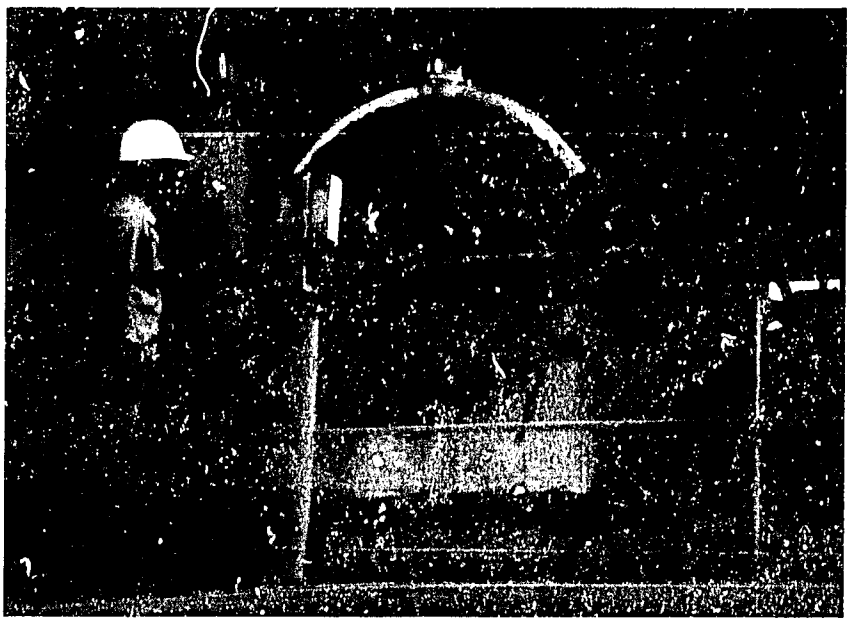
OTP was provided equipment specifications and a bid document by IFDC to secure worldwide bids for a beneficiation pilot plant to be installed at the plant site. After OTP chooses the vendor IFDC will assist in equipment installation, initial startup, and training of OTP personnel.

Phosphate Rock Studies

Some exploratory studies were made in laboratory-scale equipment with the objective of improving the quality of phosphate ore and products made from it. This was to assist OTP in better meeting future market demands.

NPK Technical/Economic Assessment

OTP is considering diversification of its operations in the future to allow the manufacture of value-added intermediates and products. IFDC prepared a preliminary technical and economic assessment of three schemes to produce NPK fertilizer using Togo phosphate concentrate and other raw materials. The plant would serve the needs of Togo and other countries in the region. The phosphate would be converted to an agronomically acceptable form based on partial acidulation.



A fertilizer plant worker observes the operation of centrifuges, which are used to wash and dewater phosphate concentrate at the OTP facility at Kpeme.

Sustaining Asia's Accomplishments

Laborers transplant a cooperative rice experiment conducted by the Thailand Department of Agriculture and IFDC at Pathum Thani, Thailand.

"Drifting to disaster only 10 years ago, agriculture in the Asia-Pacific region has registered 'vast progress' since then, but mass poverty and malnutrition affecting 300 million people still pose serious problems," said Edouard Souma, Director-General of the United Nations Food and Agriculture Organization.

"Drifting to disaster only 10 years ago, agriculture in the Asia-Pacific region has registered 'vast progress' since then, but mass poverty and malnutrition affecting 300 million people still pose serious problems," said Edouard Souma, Director-General of the United Nations Food and Agriculture Organization.

Only a decade ago, Asia was threatened by huge food deficits, with cereal shortfalls forecasted to reach 35 million tonnes by 1985. To make up the difference, the imports of food had quadrupled. However, since that time, total cereal production has increased at an annual rate of 3.7%. Now the region is a net exporter of rice, and increases in wheat yields have stabilized imports.

Several factors contributed to this success; according to Souma these include the dismantling of policies that discriminated against farmers, the increased flow of resources to agriculture, better technology, the supply of inputs, improved marketing facilities, reform of bureaucracies, and strengthened research. As Souma points out though, there are still serious problems, especially due to the fact that agricultural growth has been uneven and that the region is already approaching the limits of its arable land.

Even though Asia has made noticeable progress in increasing its food production, it has been slow to improve the access to food by the vulnerable segments of its population. Millions of people in the region are still undernourished, primarily because of poverty.

Despite the exponential growth during the past two decades, food-grain production has stagnated. Yields have leveled off in spite of increased application of nitrogen. What is needed now is a stronger focus on balanced nutrition. While nitrogen is clearly the primary fuel for the crop production machine—phosphorus, potassium, magnesium, calcium, sulfur, and a number of micronutrients are

needed in increasing amounts not only to maintain but also to increase the natural fertility of the soil. We now need to look beyond what has been achieved with seeds and fertilizer and direct more of our attention to the soil characteristics in an effort to supply a more balanced nutrient package and, thus, make it possible to achieve another "Green Revolution" during the next century. Such a breakthrough in crop yields is needed if one accepts the prediction that the world's requirement for additional food will increase by about 60% during the next 20 years. Since 80% of Asia's arable land area is now under cultivation, its additional food requirements will have to come from increased yields.

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Fertilizer will play a vital role in helping Asia sustain its food production levels into the next century. In fueling the crop production machine, Asia has all of the elements needed for continued rapid growth in fertilizer consumption. It has a large, diligent and rapidly growing population, a food demand growing at a faster rate than the population, and a low potential to open up new land for food production.

The challenges confronting Asia's fertilizer industry are manifold. One of the big challenges of the future will be to find a proper response to expected changes in people's diet. More effort must be directed towards the increased production of other food such as fruits, vegetables, and animal products. Such diversification will also require changes in the types of fertilizers and application methods to be used. With fertilizer use now extending more and more into an increasing spectrum of various upland crops, nutrients other than nitrogen will gain in importance. The next decades will, therefore, see the need for a diversification of the supply of fertilizers with multinutrient fertilizers gaining in importance. Additionally, greater attention will need to be placed on assessing the impact that fertilizers have on the environment and technologies developed to ensure that this valuable input is used effectively in establishing a sustainable agriculture for the region. Through its programs in research, technical assistance, and training, IFDC continues to help Asian countries meet these new challenges.

Research Activities

Nitrogen Research

Experimental Materials

IFDC has the unique capability of supplying agronomic researchers with a wide range of experimental materials to support the laboratory, greenhouse, and Asian field programs. In general, IFDC has concentrated its research on solid forms of fertilizers with no emphasis on liquid or suspension fertilizers. Further, there has been research along the single nutrient type (such as nitrogen, phosphorus, and sulfur). This trend continued in 1987, and urea was emphasized due to its importance in Asia. Much of the work involved studies to improve use efficiency and increase yields.

Several techniques (mainly laboratory scale) are used for material preparation. Certain materials such as ^{15}N-labeled urea and inhibitors are extremely expensive, and losses must be kept to the minimum.

Tabletting—Tabletting is often used to combine urea (unlabeled or ^{15}N labeled) with other materials such as urease or nitrification inhibitors or even other nutrient carriers such as ammonium sulfate or elemental sulfur. Tablets can be made in various sizes. The solid dry ingredients are well mixed and fed continuously to the tabletting machine where products are made automatically. Thus, the tabletted particle is homogenous, and the additive is distributed uniformly throughout the particle.

Coated Products—Coated products are made to control the rate of nutrient release or to add small amounts of inhibitor. The coating may be applied as a melt, from a solid in solution, or from reacting chemicals. The substrate (material to be coated) is often urea due to the emphasis on improved use efficiency, but NP or NPK granular fertilizers have also been coated. Coatings may be inhibitors (solid powders), polymers, waxes, and resins (natural and synthetic).

Much of IFDC's Headquarters' research on nitrogen has focused on the evaluation of urease inhibitors and their potential for use in the tropics. (Urease inhibitors reduce the nitrogen losses to the atmosphere during the conversion of urea to ammonia.)

See page 31 for information on field evaluation of these coated products.

Compaction—Compaction of solid dry powders into granules is used to supply larger quantities of mixtures and when less expensive materials are used rather than tabletted products. Losses are relatively low and drying and cooling are avoided for heat-sensitive materials.

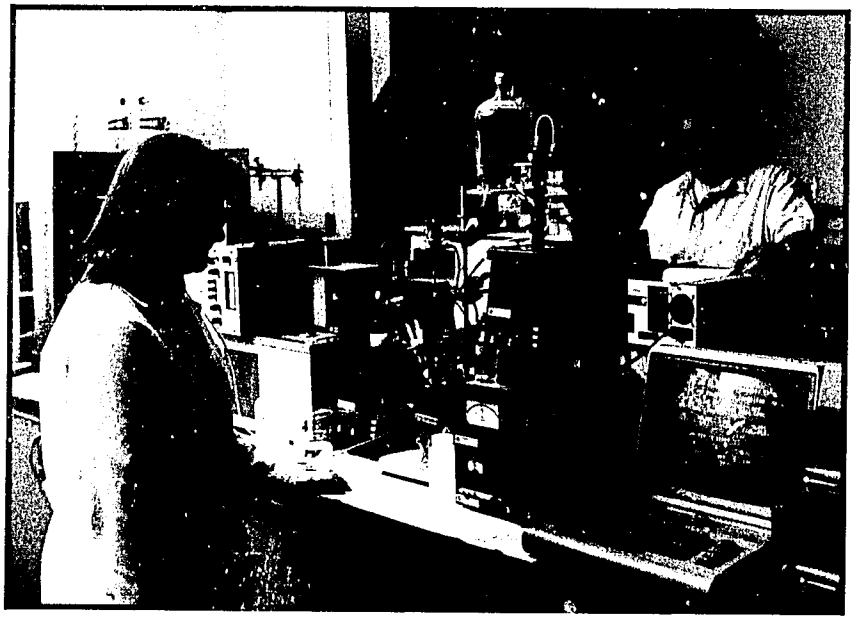
Granulation—Granulation by melt or wet-chemical methods is also used to prepare experimental materials. Usually, drying and/or cooling are required. Granules are homogenous and may be made in various sizes.

Vanessa E. Keel, Chemical Laboratory Analyst, and Steve Coonrod, Chemical Laboratory Analyst of the National Fertilizer Development Center (temporarily assisting IFDC on a reimbursable basis), perform laboratory tests to evaluate potential urease inhibitors.

Amended Urea Types

Two basic types of amended urea were used in the agronomic test program during 1987—USG and urea plus urease inhibitor.

Urea Supergranules—A method to make USG from prilled urea in Asia is needed based on simple technology and relatively low cost. An IFDC engineer further evaluated a briquetting machine available from the People's Republic of China and made improvements to achieve sustained production of 1-g USG at 250 kg/h. This was done in collaboration with the Agency for Agricultural Research and Development (AARD), the Center for Soil Research (CSR), and the Metal Industries Development Center (MIDC) in Indonesia. The concept involves delivery of prilled urea to a distribution point in bulk or bagged form. Prilled urea is fed to the briquetting machine where two rolls under pressure form the briquettes, which are separated by screening; off-size material and dust are returned to the briquetter. Briquettes are sold in quantities needed by the farmer for deep placement. (See also "National Programs—Indonesia," p. 36.)



Urease Inhibitors to Increase Nitrogen Efficiency—The use of urea has grown tremendously in recent years because it is the least expensive and highest analysis solid nitrogen fertilizer. Urea is generally not taken up by plants directly but must first be converted to ammonium nitrogen. This conversion is effected by a urease enzyme that is of biological origin and is present in different amounts in soils. In soils with high amounts of urease due to high biological activity, the rapid conversion of urea to ammonium can cause high concentrations of ammonia near the soil surface, bringing about high losses of the applied urea nitrogen through ammonia volatilization. Soils that have high urease activities at the soil surface are many flooded soils and those that have not been tilled for a long period. Therefore, urea applied to flooded soils, plantation crops (cacao, coffee, tea, palm oil, and rubber), or to young crops may be susceptible to large ammonia volatilization losses.

An approach to decrease losses due to rapid conversion of urea is by the use of urease enzyme inhibitors. Inhibitors of the enzyme urease may be useful in reducing nitrogen losses by slowing the conversion of urea to ammonia. Since ammonia losses depend on the rate of ammonia formation, these inhibitors could be very effective in increasing nitrogen efficiency. Previously, the most promising urease inhibitor had been phenyl phosphorodiamidate (PPDA), but its effect in flooded soils lasted only 3-4 days, after which urea conversion was again very rapid.

Much of IFDC's Headquarters research on nitrogen has focused on the evaluation of urease inhibitors and their potential for use in the tropics. A newly identified class of urease inhibitors is the phosphoric triamides, which are

quite similar to the structure of PPDA. One compound of the class is N-(n-butyl) thiophosphoric triamide (nBTPT), which has been tested in soils and found to have sustained inhibition. In Headquarters greenhouse experiments conducted in previous years, nBTPT has consistently kept ammonium concentrations from developing in the floodwater, while PPDA has failed after a few days, allowing ammonia to accumulate and be lost via volatilization.

In two Headquarters greenhouse experiments conducted in 1987 with flooded rice in which the fertilizer was applied 15 days after transplanting, a common practice of Asian farmers, fertilizer losses were about 50% when urea was used by itself. With PPDA the loss was about 30%, and with nBTPT losses were from 10% to 17%. As would be expected by decreasing losses, the plant recovery of the nitrogen was increased by the inhibitors and about doubled with the nBTPT. Grain yield was not significantly increased by the use of PPDA, but it was by the use of nBTPT.

In some upland soil systems urea is applied on the soil surface, and if the soil has developed a high urease activity, ammonia volatilization from urea applications can be very high. A urease inhibitor can be used to reduce these ammonia volatilization losses. In a 1987 experiment conducted in a Headquarters greenhouse using Guthrie soil to which 1% lime was added, losses were decreased as more nBTPT was added. If the amount of nBTPT was 0.1% or more, losses were kept at less than 10% of the urea added.

The rate of inhibitor necessary to decrease losses to an acceptable level will depend on the urease activity of the soil as well as other soil characteristics. The urease activity of two soils was increased by addition of straw, which increased its biological activity. With straw addition both soils lost about 45% of the urea-nitrogen in 8 days. Without straw addition losses were about 37% with one soil and only 6% with the other. When nBTPT was added at different amounts, the amount of ammonia volatilization that occurred was very dependent on the soil characteristics as well as the amount of nBTPT added. For soils with high urease activity due to straw addition, 0.1% nBTPT was enough to keep losses below 10% of the nitrogen, but with lower urease activities, 0.01% nBTPT was sufficient.

Research on the potential of urease inhibitors to increase nitrogen efficiency will be expanded in 1988 to include collaborative field studies with 15 national and international research organizations. Trials will be conducted on both flooded rice and upland crops, particularly plantation crops. In addition, work is underway to identify new families of chemical compounds that could serve as urease inhibitors.

Preliminary studies have already begun to identify other urease inhibitors of the phosphoric triamide group that are more powerful than nBTPT. During 1988 efforts at Headquarters will attempt to determine the rates of these inhibitors necessary to achieve particular reductions in ammonia volatilization, the effects of soil characteristics on inhibitor performance, and the stability of the inhibitors when incorporated in urea fertilizers.

Urea Supergranules Tested in India

Researchers generally agree that under proper soil and cropping conditions, deep placement of urea improves use efficiency and results in increased yield of paddy rice. Over several years IFDC has described this technology and presented yield results obtained by researchers using their methods of evaluation. The "researcher's method" involves conventional line transplanting, followed by deep placement of USG a few days after line transplanting.

Researchers generally agree that under proper soil and cropping conditions, deep placement of urea improves use efficiency and results in increased yield of paddy rice.

As reported previously, IFDC has developed a USG dispenser method combining deep placement and line transplanting in an attempt to save labor without reducing yield. The technology is aimed primarily at the small farmer who can only afford small amounts of nitrogen.

In 1987 during the Kharif season, 15 trials were conducted by IFDC in collaboration with Indian researchers on the fields of small rice farmers using the IFDC dispenser method and capitalizing on the farmers' management skills. Trials were carried out in the Konkan region of Maharashtra State, India, in collaboration with Konkan Krishi Vidyaputh (KKV) and the Indian Farmers Fertilizer Cooperative, Ltd. (IFFCO). Dispersers were fabricated in a KKV workshop and in the workshop of the Yusuf Meherally Center

at Tara Village. The 1-g USG were supplied as cylindrical tablets by IFFCO.

The IFDC dispenser method consisted of line transplanting with 15 x 20 cm spacing and hand deep placement of 1 USG for every 4 hills (38 kg nitrogen/ha) using the IFDC dispenser with transplanting guide. The farmer's method varied but usually consisted of random transplanting with uncontrollable spacing, geometry, and plant population; urea as prills was applied in one or two applications onto the soil surface. The crops in all trials were grown completely under rainfed conditions with no supplemental irrigation.

In these initial studies labor requirement for transplanting and fertilizer application was quite variable for both methods. In general, the farmers were able to use their method with less labor since the dispenser method requires some training and skill to achieve proficiency. On the average the dispenser/line transplanting method required 7 workdays per hectare more than the farmer's method of planting rice and broadcasting urea. This differential may be reduced with further experience.

Grain yields in 11 of 15 trials where valid comparisons could be made showed a yield increase (average) of 480 kg/ha or 15% for the IFDC dispenser method compared with the farmer's method. Further trials with farmers are needed to determine if they will adapt the method providing that an additional 500 kg/ha of rice is produced at an increased labor requirement of up to 7 workdays and a fertilizer premium of up to 10% over prilled urea broadcast in the floodwater.

Nitrogen Use Efficiency Furthered in Indian Semiarid Tropics

In the semiarid tropical (SAT) environments, crop yields are generally hindered by the lack of available moisture arising from a high atmospheric water demand and limited water resources. Apart from moisture deficiency, SAT soils are deficient in nitrogen, phosphorus, and zinc. Among these three plant nutrients, deficiency of nitrogen is universal. Past research conducted under this program has established a positive and significant response to fertilizer-nitrogen of crops grown on SAT soils. Another notable contribution of the nitrogen research program was that the use efficiency of nitrogen fertilizers by SAT crops depended heavily on effective soil depth. With deep soils (effective soil depth >1 m) the nitrogen-use efficiency by crops, contrary to the generally held belief, was high and nitrogen loss from the soil-crop system was low (<10%). The situation with shallow soils (effective soil depth ≤50 cm) was, however, different since nitrogen use efficiency was low and nitrogen loss was typically high (≅30%). Our past research could not identify the exact mechanism of nitrogen loss although we speculated leaching and denitrification were important pathways of nitrogen loss. We initiated research on this aspect.

A study (in collaboration with ICRISAT) with sorghum as a test crop was conducted on a shallow Vertisol at the ICRISAT Farm in Hyderabad, India. The objective of this experiment was to identify the dominant nitrogen loss mechanism through selection and identification of the proper nitrogen source. Test fertilizers included urea, urea-DCD (urea treated with dicyandiamide, a nitrification inhibitor), urea-PPD (urea treated with phenyl phosphorodiamidate, a urease inhibitor), and potassium nitrate. All fertilizer sources were applied to correspond to 30, 60, and 90 kg nitrogen/ha rates (one-half basal at the time of seeding and one-half topdressed 1 month later). Sixty kilograms of nitrogen/ha rate was labeled with ^{15}N. A no-nitrogen zero rate was also included. Phosphorus (40 kg P_2O_5/ha through SSP) and zinc (5 kg zinc/ha through zinc sulfate) were applied across all experimental plots as basal dressing.

The rainfall during the cropping season was low—370 mm. It represented only two-thirds of the average rainfall for this region. Despite near drought conditions, the distribution of rainfall over the entire cropping season was satisfactory.

Data on grain yields (averaged across sources) presented in Figure 6 show that nitrogen application to sorghum grown on a shallow Vertisol caused a significant increase in yield. Without nitrogen application, the sorghum grain yield was only 1.5 tonnes/ha. With nitrogen application, depending upon the rate of nitrogen application, it was 2-3 times greater. At 60 kg nitrogen/ha, the commonly recommended rate of nitrogen application, each kilogram of nitrogen produced 37 kg of sorghum grain. These results confirmed our previous conclusions that a remarkable potential for improving crop yields exists through nitrogen fertilization of crops grown on the Vertisols of the SAT. Despite near-drought conditions, a large increase in grain yield resulting from nitrogen fertilizers once again contradicts the past supposition on excessive risks associated

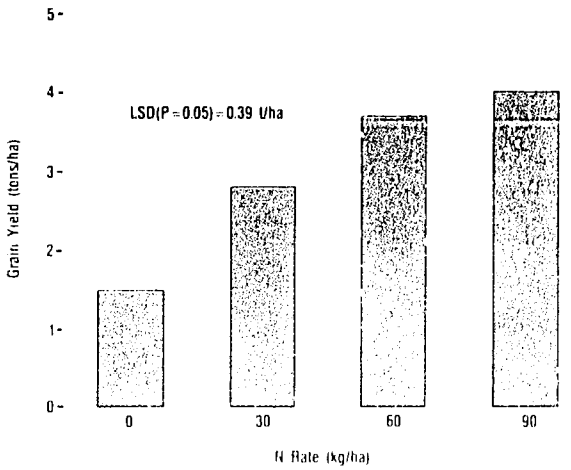


Figure 6. Effect of Nitrogen Application on Sorghum Grain Yield (Shallow Vertisol).

with using nitrogen fertilizers in rainfed agriculture.

Irrespective of the rate of nitrogen application, grain yield response to fertilizer nitrogen remained unaltered, whether the source of nitrogen was urea or potassium nitrate (Figure 7). Also treatment of urea with PPD or DCD did not influence the grain yield response. The

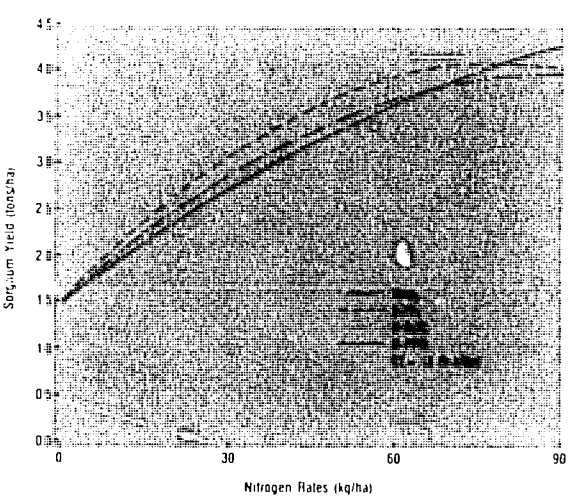


Figure 7. Sorghum Response to Nitrogen Sources (1987).

lack of difference between urea treated with DCD—a nitrification inhibitor and potassium nitrate—a source vulnerable to denitrification and leaching, suggested that denitrification and leaching were not important mechanisms of nitrogen loss. In addition, the equal performance of urea and urea treated with PPD—a urease inhibitor—suggested that ammonia volatilization was also not an important mechanism of nitrogen loss on shallow Vertisols.

Failure of urea to outperform potassium nitrate is in variance with the findings of our previous research (crop year 1984) conducted also on a shallow Vertisol at the ICRISAT farm. In that study potassium nitrate-nitrogen was more vulnerable to loss compared with urea-nitrogen (60% nitrogen loss with potassium nitrate versus 30% with urea). Accordingly, with potassium nitrate the yield of sorghum dropped by 700 kg/ha. Since the important soil characteristics where research during 1984 and 1987 was located did not vary significantly, we investigated the possibility that the seasonal rainfall and its distribution accounted for the inconsistency in the relative performance of urea and potassium nitrate across years.

Rainfall—the only source of water for dryland crops—can considerably moderate the losses of nitrogen by affecting fertilizer transformations and mobility. This contention is borne out of our research conducted on artificially created shallow and deep soils in the controlled environment of a greenhouse. Houston clay, a Vertisol more or less similar in important characteristics to Vertisols occurring in India, was the experimental soil. The rate and method of application of the test fertilizers were similar to those imposed in the field experiment. To simulate different rainfall intensities, water was added periodically in single pulses varying between 5 mm and 40 mm. Over a period of 28 days, irrigation water equaled 185 mm rainfall. Since the fertilizer sources were labeled with ^{15}N, it was possible to trace their fate at the conclusion of the experiment. Nitrogen-15 balances showed a strong interactive influence of nitrogen source and soil depth on nitrogen loss (Table 5). With relatively deep soil (soil depth 40 cm), the nitrogen loss was low (<10%); this loss did not differ significantly between urea and potassium nitrate. In sharp contrast, with relatively shallow soil (soil depth 20 cm), the nitrogen loss was high. It was unusually high when potassium nitrate was the nitrogen source. For example, nitrogen loss from potassium nitrate was 55% corresponding to only 10% from urea. These results on increasing susceptibility of potassium nitrate with decreasing soil depth parallel our past findings obtained in the field on shallow and deep Vertisols of the Indian SAT.

Differential soil moisture regimes mediated through soil depth appeared to be the key factor explaining the variable nitrogen loss from urea and potassium nitrate. Visual observations on soil cracking, supported by moisture estimates (Figure 8) and occurrence of percolation,

Table 5.
Effect of Topsoil Depth on the Recovery and Loss of ^{15}N From Different Fertilizer Sources

	^{15}N Recovery %		^{15}N Loss %	
	Topsoil Depth (cm)		Topsoil Depth (cm)	
Fertilizer Source	20	40	20	40
Potassium nitrate	45	92	55	8
Urea	90	95	10	5
Urea-DCD	93	92	7	8
Urea-PPD	94	100	6	0

suggested that at the same level of irrigation, shallow-depth soil became saturated, while the deep soil remained unsaturated. In the absence of any significant leaching loss of nitrogen (leaching loss = <0.5%), saturated conditions appeared to dominantly control nitrogen loss from shallow soils. Fractional analysis of soil nitrogen forms further suggested that the transformations of urea-nitrogen and potassium nitrate-nitrogen were influenced by saturation. The impact of soil saturation on nitrogen loss and nitrogen transformations arose from anoxic soil environment, which is known to follow saturation. As a result, nitrification, an aerobic process, is obstructed and denitrification, a process of anaerobic environment, is promoted. Apparently, prevalence of saturated conditions in shallow depth soil might have protected urea-nitrogen from loss by decelerating nitrification of ammonium-nitrogen (a product of urea hydrolysis) and made potassium nitrate more prone to denitrification and heavy nitrogen loss. With unsaturated deep soil, the denitrification was constrained due to absence of anaerobic environment. Consequently, in marked variance to shallow saturated soil, nitrogen loss from urea and potassium nitrate did not differ from deep unsaturated soil. Regardless of soil depth, ammonia volatilization appeared to be unimportant because of fertilizer placement. Negligible loss of nitrogen with or without treatment of urea with PPD, a urease inhibitor, was an additional evidence supporting nonoccurrence of ammonia volatilization.

Thus, on all accounts it appears that soil saturation associated with shallow-depth soils causes denitrification, supposedly the major nitrogen loss mechanism. In the absence of soil saturation, nitrogen loss from shallow soils, as is the case with deep soils, is expected to be low and consistent across different nitrogen fertilizers. During 1984 (while measurements are not available to confirm it) a heavy rainfall at the

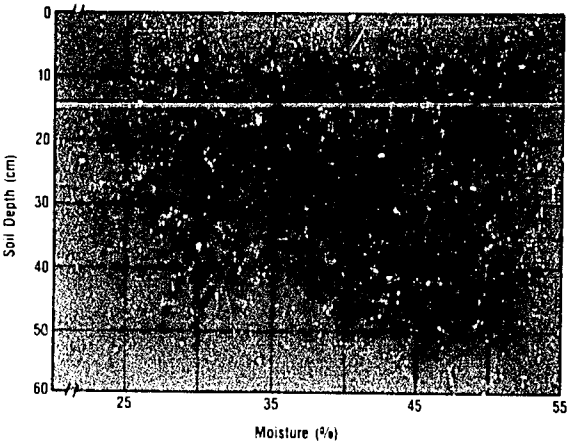


Figure 8. Influence of Topsoil Depth on the Distribution of Moisture in the Soil Profile.

time of fertilization may have led to sufficient moisture in the surface layer of the shallow soil to promote greater denitrification from potassium nitrate than from urea. Nitrogen loss with potassium nitrate was twice as great as it was with urea. Compared with the 1984 cropping season, rainfall during 1987 was low and well distributed. Under these rainfall conditions potassium nitrate might not have become prone to denitrification; consequently, agronomic performance of urea and potassium nitrate did not differ (Figure 7). The lack of difference between urea treated with DCD—a nitrification inhibitor—and potassium nitrate was an indirect evidence precluding the possibility of denitrification in a low rainfall year.

In conclusion, performance of nitrate-(potassium nitrate, calcium ammonium nitrate, nitrophosphate, ammonium nitrate) containing fertilizers *vis-a-vis* amide-(urea) or ammonium-(diammonium phosphate, ammonium sulfate) containing fertilizers will depend upon rainfall distribution, particularly its extent at the time of fertilization of shallow soils of the SAT. During high rainfall years, nitrate-containing fertilizers will be a poor choice when compared with urea.

Nitrogen Use Efficiency Studied in the Philippines

Since nitrogen is frequently the most limiting nutrient for irrigated rice in Asia, the application of nitrogen is essential to sustain high rice yields. However, the nitrogen fertilizer applied to irrigated rice is prone to high losses and low utilization by rice. In 1987 IFDC continued to collaborate with the International Rice Research Institute (IRRI) in the Philippines in the development of technologies that sustain

increased rice production while increasing the efficiency of fertilizer inputs.

In 1987 IFDC continued to collaborate with the International Rice Research Institute (IRRI) in the Philippines in the development of technologies that sustain increased rice production while increasing the efficiency of fertilizer inputs.

Potential of Biological Inhibitors in Lowland Rice—Data from Philippine field research was used to estimate potential urea savings possible with a hypothetically ideal inhibitor that would completely eliminate gaseous nitrogen loss of applied urea under the conditions of those experiments.

The potential urea savings with an ideal inhibitor was assumed to equal the gaseous loss of nitrogen from applied urea. At this particular study site, total gaseous loss of nitrogen and, hence, potential urea savings averaged over two dry seasons increased with nitrogen application rate. It ranged from approximately 15% for 30 kg urea-nitrogen/ha to approximately 33% for 120 kg urea-nitrogen/ha. The response in grain yield to applied urea was 2.0 tonnes/ha with 60 kg nitrogen/ha and 2.8 tonnes/ha with 120 kg nitrogen/ha. The hypothetical increase in the response curves due to nitrogen application was estimated assuming that the full potential in urea savings through elimination of gaseous nitrogen loss could be obtained. At this site the maximum possible increase in rice yield with an inhibitor that eliminated nitrogen loss with no effect on the rice other than increasing availability of fertilizer nitrogen was 6% and 8% in the two seasons.

The findings and research methodologies employed in this study will aid in the determination of a maximum acceptable additional cost of amending urea with inhibitors. It could also assist in the identification of rice-growing environments in which inhibitors would have the greatest economic potential.

Effectiveness of Urea Coatings in Lowland Rice—Urea coatings that slow the release of nitrogen offer another possible strategy for increasing the efficiency of urea fertilizer applied to rice. Sulfur-coated urea has been widely evaluated and shown to be an effective nitrogen fertilizer for rice, but it has been too expensive for use on most field crops.

One option for reducing the cost of coated urea is to use alternative, lighter weight coatings. Three experimental polymer-coated fertilizers ranging in coating weight from 3.3% to 6.0% were prepared with 4.4-mm diameter granular urea and evaluated in the field. All three polymer-coated fertilizers were as effective as 2.0-mm diameter sulfur-coated urea (20% coating weight, 21% 7-day release in water) in reducing nitrogen fertilizer loss.

Mean grain yields for the three polymer-coated fertilizers were between 0.1 to 0.7 tonnes/ha greater than for prilled urea applied

A research assistant at IRRI (Evelyn V. Flordelis) collects gas samples to measure nitrogen loss by denitrification from a rice field in Muñoz, Nueva Ecija, Philippines.

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by the best recommended practice. Research has shown that coating urea with polymer can dramatically reduce the quantity of urea required to obtain desired grain yields. Of the three fertilizers tested, the 3.3% coating weight was most effective. Grain yields with the 3.3% polymer-coated urea and 2.0-mm diameter sulfur-coated urea were the same. These findings suggest that alternative light-weight coatings can be agronomically as effective as sulfur coatings.

Direct Field Measurement of Denitrification—Denitrification is a biological process by which soil and fertilizer nitrogen can be lost to the atmosphere as nitrogen gas. It has long been considered as a major mechanism of nitrogen loss in flooded rice soils. However, the magnitude and importance of denitrification have not been quantified because a suitable method for field measurement of denitrification has not been available. IFDC scientists recently developed a method for estimation of denitrification losses, and this method was used at three sites in the Philippines in a collaborative project with IRRI.

At each site the directly measured nitrogen gas loss from urea fertilizer was 1% or less of the applied nitrogen. These nitrogen losses by denitrification are much lower than those previously estimated by other indirect techniques. The findings reveal that considerable scope still exists for improvement of field techniques to measure nitrogen loss.

Sulfur Research

IFDC/Thailand Department of Agriculture Cooperative Research Project

In 1986 IFDC began collaborative research with the Nuclear Research in Agriculture Branch of the Thai Department of Agriculture with the establishment of an experiment in northeast Thailand using sources labeled with ^{35}S to determine fertilizer sulfur balances, leaching rates, and fate of sulfur in rainfed rice. Although deficiencies of sulfur are often reported on the sandy soils of this region, sulfur fertilizers had no effect on final yield in the 1986 experiment. Results from ^{35}S-balance experiments, however, showed that fertilizer sulfur recovery from incorporated SSP and SGT[illegible] by rainfed rice was very poor (4%-8%). For both sources, only 60%-62% of the applied sulfur was recovered from the roots and soil profile to a depth of 90 cm leaving approximately 30% of the fertilizer sulfur unaccounted for. Although leaching of sulfur may account for some of the losses from this sandy loam soil, transportation in the floodwater, which inundated the plots following a heavy rainfall may also have been an important loss mechanism. Low recoveries and loss mechanisms are being further investigated in followup collaboration.

Technical Assistance

Bangladesh

As is the case with other developing countries, Bangladesh is meeting and conquering the challenges of a changing agricultural situation. Because of its accomplishments in restructuring its fertilizer distribution system, Bangladesh may soon serve as a model for privatization of fertilizer sectors in other developing countries.

During 1987 IFDC participated in a World Bank Mission designed to review the Bangladesh fertilizer sector. The objectives of the Mission were to update the Bank's knowledge of the sector, evaluate the developments in the sector, and identify the primary sector issues and policy considerations. The Mission members discussed with the Government its plans for further improvements in the performance of the sector and the role that the Bank can play in assisting the Government. The competitiveness of the existing products and possible measures that can be taken to improve the economic viability of domestic production units were evaluated. The Mission reviewed plans for capacity expansions in the sector and discussed with the Government possible changes in the ex-factory pricing system.

The Mission made several recommendations to the Government to further develop a cost-effective and socially sensitive fertilizer sector. The establishment of a monitoring and evaluation system was recommended to ensure the efficient operation of the fertilizer sector. It was also recommended that a uniform pricing policy be established from the production units owned by the Bangladesh Chemical Industries Corporation (BCIC) and the transportation discount points (TDPs) of the Bangladesh Agricultural Development Corporation (BADC). In order to alleviate the unfavorable debt-to-equity ratio, the Mission proposed that the Government consider absorbing all or a portion of some foreign loans to fertilizer plants and converting that amount into equity in the fertilizer plants.

There is growing evidence that the present mix of fertilizer (urea, TSP, and muriate of potash) will not sustain the nutritional requirements of an agriculture that is becoming progressively more intensive and diversified. In fact, the recent slowing in growth of crop productivity may, at least in part, be directly linked to the growing evidence of crop nutritional disorders of sulfur and zinc. The Mission therefore recommended that the Government reexamine the required fertilizer product mix and determine the most effective way of obtaining supplies to sustain an increasingly intensive and diversified agriculture. It was recommended that special attention be given to the merits of domestic production versus importation of urea/sulfur, NP, elemental sulfur, and NPK sulfur combinations.

The Mission further recommended that future fertilizer plant expansions should consider locating urea plants within the area of market demand rather than in the area of raw material supply. Extending the nation's natural gas pipeline into the market area may reduce transportation costs and significantly relieve pressures or the infrastructure (railroads, roads, barges) already stressed from moving large quantities of fertilizer and other commodities.

It was projected that Bangladesh would be self-sufficient in the production of urea by February 1988. In fact, the country will have a net surplus of urea. The Mission, taking note of currently depressed international prices of urea, recommended that a program be developed to use this production to stimulate domestic consumption of nitrogen and thus move toward self-sufficiency in rice and wheat rather than exporting the surplus fertilizer at prices below cost of production.

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Burma

During 1987 an IFDC-directed study team was commissioned to evaluate Burma's fertilizer sector and find ways to increase its effectiveness. This project, funded by USAID, was conducted under a subcontract with the South-East Consortium for International Development.

Burma is faced with some difficult choices that will have a strong impact on the future growth of the country's fertilizer sector. The most significant choice concerns the policies related to the production of rice and upland crops and allocation of limited supplies of fertilizer. Because the Government of Burma has recognized the need for expanded production of crops other than paddy, it has introduced a program of agricultural diversification to expand the production of 19 upland crops. However, this will take time and an increased amount of fertilizer. For the present, the Government faces a serious foreign exchange crisis and must make some difficult choices. Significant though small increases in foreign exchange earnings can be generated over the short term by exporting surplus urea whereas larger increases can be realized over the long term by allocating this fertilizer for use on rice and upland crops.

The team recommended that Burma shift from exporting its surplus urea fertilizer to using the fertilizer domestically to increase the production of rice and oilseeds. Secondly, it was recommended that fertilizer prices at the farm level be increased to more closely approximate the actual cost. Additionally, recommendations on phosphate and potash fertilizers should reflect local conditions, taking into account differences in soil fertility, climatic

conditions, and profitability of use, particularly for upland crops. These actions will result in increased foreign exchange earnings on rice, conservation of foreign exchange by reducing the import of cooking oils, and a decrease in subsidy with a resultant increase in local currency available to the Government that could be used for priority areas of agricultural development.

The team also recommended that the efficiency of Rangoon Port be improved in regard to handling fertilizer imports. In addition, another recommendation called for an increased role of rail transport in moving fertilizer from Rangoon Port to central and upper Burma.

Further, the Government was urged to begin now in planning the construction of additional nitrogen capacity (to be commissioned by the mid-1990s) to satisfy rising domestic needs as well as generate foreign exchange by exporting surplus production on the international markets. As for raw materials, Burma has ample quantities of low-cost, good-quality natural gas.

The team suggested that these and other recommendations be integrated into a national fertilizer program.

India

An IFDC staff member participated in a World Bank team that advised the Government of India regarding improvements in its fertilizer sector, including the establishment of a network of inland rail terminals. The IFDC staff member provided advice on fertilizer transport, handling, layout options and costs, and consideration of bulk and bag movement options.

The Philippines

The Government of the Philippines has decided to carry out an extensive evaluation of USG technology and its value to smallholder rice farmers. Four pilot areas have been selected, farm surveys completed, and field trials begun. The work is being carried out by the Philippine Rice Research Institute through the Fertilizer and Pesticide Authority, both of the Department of Agriculture. IFDC has provided supplies of USG and technical assistance. An IFDC sociologist was involved in the development of a questionnaire to assess the socioeconomic constraints to the adoption of USG technology by small rice farmers. A soil scientist assisted by designing the experiments. The initial work in two provinces will be expanded to other provinces through 1989, and IFDC will continue to collaborate on the Project.

Fertilizer is one of the most important inputs for agricultural production in Bangladesh. In fact, current increases in crop production levels can be maintained only through more intensive fertilizer use on most of the soils.

Turkey

IFDC fertilizer production specialists assisted KREBS, a French engineering firm, in responding to a tender issued by a Turkish fertilizer manufacturer. The Turkish firm proposed to modify an existing granular triple superphosphate (GTSP) plant to enable the production of a number of urea-based NPK products in addition to GTSP. IFDC provided KREBS with a basic process design package for the NPK modification to enable them to respond to the tender and, if successful, perform the necessary detailed engineering for implementation of the modification project.

National Programs

Bangladesh

During 1987 the BADC/IFDC host-country technical assistance contract was initiated under the USAID-funded Fertilizer Distribution Improvement II Project (FDI-II) as a followup to the FDI-I project. IFDC's involvement in Bangladesh has been continuous since the inception of the FDI-I project in 1979 with BADC, a public-sector agricultural input marketing organization.

The goal of the FDI-II project is to increase food production by increasing fertilizer consumption through more responsive and cost-effective distribution and use of fertilizer while simultaneously continuing ensurance of adequate supplies of fertilizers nationwide. The project focuses on consolidating the marketing developments of the FDI-I project and continuing the process of developng private-sector involvement

in the distribution of fertilizers. The project seeks to expand the role of the private sector in large wholesale, competitive fertilizer procurement and to transfer fertilizer technology to farmers through fertilizer dealer development programs.

Fertilizer is one of the most important inputs for agricultural production in Bangladesh. In fact, current increases in crop production levels can be maintained only through more intensive fertilizer use on most of the soils. A recent study indicated that the annual rate of increase in rice production has been maintained at 2.43% during the past 10 years even though area under paddy leveled off during the past 5 years. Increasing the use of fertilizer accounted for about 30% of increased rice production.

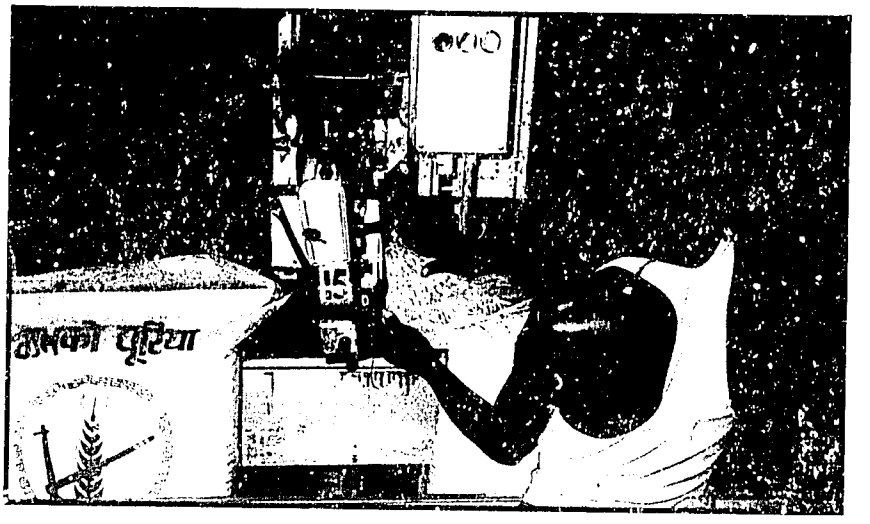
IFDC team members based in Dhaka made an assessment of fertilizer marketing in Bangladesh considering the past, present, and future in pursuance of the terms of reference for the technical assistance contract. The objective of the study was to assist BADC management in identifying problems and prospects for the future improvement in fertilizer marketing and formulating a policy based on experiences from the past.

Changes in the organizational structure are essential in order to adapt to the changing marketing system, which is required to meet the needs of Bangladesh farmers. During the first year, IFDC has assisted with identifying some redirection for BADC, including a draft reorganization.

The specific reorganization was recommended after a study of.

1. The work that BADC does now and ways that it can better assist with the development of agriculture in Bangladesh.
2. An evaluation of each work activity to determine its link to achieving the agricultural development objectives.
3. A redefinition of the work to take advantage of the unique skills within the BADC fertilizer unit.
4. A determination of reporting relationships to eliminate some line positions, reduce rigidity, and create more specialists.

Fertilizer demands have increased rapidly (about 6.5% per year) during the past few years, and distribution has become more complex. One of the major problems encountered by BADC during 1987 was distribution of fertilizer on a timely and cost-effective basis. Some problems were caused by large requirements for transportation of imported food grain following the disastrous floods in August 1987. To meet the needs of the future, the IFDC team recommended that BADC must modernize fertilizer movement, planning, and implementation. The distribution of fertilizer should be streamlined so as to fully support the private-sector involvement in the distribution of fertilizer. As a first step, BADC liberalized its marketing policy and offered wholesalers large lots of fertilizers at a wholesale discount price from six strategically located TDPs, including two local factories producing urea fertilizer. In spite of many constraints, fertilizer sales have been vigorous, particularly at these TDPs.



A fertilizer plant worker sews a fertilizer bag at the Kribhco Fertilizer Factory at Hazira, India.

IFDC has attempted to assist BADC with solving supply and distribution problems by continuous monitoring of supply/demand conditions and advising BADC of potential problems and alternative solutions. The introduction of a TDP system will ultimately provide for increased private-sector involvement replacing the public sector in district-level fertilizer marketing and distribution. IFDC visualizes that within a reasonable time period competition among wholesalers will result in improved distribution of fertilizer and overall cost savings for farmers.

The IFDC team based in Dhaka continued to advise and assist BADC's dealer development and training office in close monitoring of followup activities. A team composed of three specialists from Management Systems International and one IFDC Headquarters staff member designed a monitoring, evaluation, and reporting system for the Bangladesh fertilizer sector. Also, the IFDC/Dhaka staff provided considerable assistance in the design of the system. Since the project is designed to leave behind an

essentially self-regulating competitive fertilizer distribution sector, the logframe for the FDI-II project was expanded to reflect objectives and information needs of all major components of the fertilizer sector (fertilizer dealers, banks, government agencies, and donors). Certain key objectives and indicators were reformulated to change them to a monitorable form. The proposed system includes only minor modifications in the ongoing or planned project monitoring and evaluation but does give a detailed outline for systematically collecting and providing needed information for making management decisions in all segments of the fertilizer sector.

Aside from dealer followup and increased support from BADC high-level officials, two topics of new training programs were identified to be relevant. The first was a training program for the wholesalers who service a region or division. Second, the traditional monthly programs need to be replaced by six crop-oriented training programs per year for small dealers. Crop-oriented programs being considered are the programs for Aus, Aman, Boro (paddy) wheat, winter vegetables, potato, and summer vegetables. Tentative curricula for the large wholesalers' training program have been identified. However, program length, time allocation among topics, and methods/materials for training are yet to be determined. For crop-oriented programs, a program length of one day is being considered and curricula are being developed.

IFDC looks forward to its second year in assisting the project and confidently anticipates accelerated and intensified competition in the fertilizer marketplace.

Indonesia

The collaborative work between IFDC and AARD, which began in 1982, took on new meaning in 1987 as the national economy encountered major constraints.

The drop in export-generated revenues due to low international prices of oil and industrial crops has placed considerable stress on financial reserves of the Government and the operating budgets of the various Ministries within the Government. Specific concern has been raised regarding the cost of the fertilizer sector to the national economy.

Historically, the Government of Indonesia (GOI) has viewed the fertilizer industry as strategic to achieve its basic food self-sufficiency objective. During the past two decades, industry has aimed to fulfill the GOI's major objective of increasing domestic production of fertilizer and delivering it to the farmers at highly subsidized prices. The main industry focus has been to increase capacity and production to meet increased demand and substitute for imports (only 5% of fertilizer sales in 1987). As a result of these policies, fertilizer subsidies soared. The subsidy paid by the GOI to the fertilizer sector in 1986/87 fertilizer year totaled Rp 583 billion (US $500 million). Average subsidy per ton of fertilizer used was Rp 128,000 (US $80) for all products with that for TSP averaging Rp 229,000 (US $143) or about 50% of the total fertilizer subsidy.

The recent decision of the Government to drastically reduce the financial burden of fertilizer subsidies has placed great urgency on the National Program on Fertilizer Efficiency and specifically AARD to identify ways in which increased fertilizer efficiency at all levels can minimize the impact that increased fertilizer prices will have on crop production.

Work done earlier in the joint AARD/IFDC Project had revealed that on the acid P-responsive soils of Sumatra finely ground phosphate rock of medium to high reactivity was agronomically equal to TSP or partially acidulated phosphate rock in supplying phosphorus for maize, rice, soybeans, cowpeas, and cassava.

Studies were begun in 1987 to ascertain where and under what conditions medium to highly reactive rock would be competitive with domestically produced and/or imported TSP. Preliminary analysis has revealed that P_2O_5 in the form of phosphate rock can be delivered to the farmer in Sumatra at 27% below the cost of a similar amount of P_2O_5 supplied as imported TSP. Most importantly both imported phosphate rock and imported TSP were more cost-effective means of supplying unsubsidized TSP than phosphate from domestic production. These findings have a very important bearing on the Government's strategy to reduce the financial burden without impairing targets for food production. Clearly phosphate rock for direct application has a strong potential in Sumatra to achieve Government goals in an unsubsidized environment. To further evaluate this potential, investigations were also launched to determine the importance of grinding phosphate rock of high reactivity. Seven field sites were selected in Sumatra where phosphate rock of various sources,

ground and unground (run of mine), are being compared under a variety of agroclimatic conditions.

Work also continued on finding a low-cost means of supplying USG to the rice farmers of Indonesia. This was the main bottleneck in getting USG technologies used by the farmer. (Note: Earlier work had shown deep placement of USG could produce the same rice yields as broadcasting of prilled urea with 40% less nitrogen.) Considerable work was done with CSR of AARD and MIDC in testing a Chinese-made village-level briquetter for producing USG. It can be concluded from this work that a relatively simple and economical technology has been found to fabricate small-scale briquetters that will produce USG at an affordable price for farmers. Some of the benefits expected to arise from this technology are as follows:

1. With USG the small farmers willing to hand deep place USG will be able to save money by using less fertilizer or by producing more rice using the same amount of fertilizer.
2. A new small-scale industry to manufacture briquetters will develop, thereby generating new jobs in rural areas.
3. The USG producer will benefit from an increased income, which will raise his standard of living.
4. Reducing the nitrogen losses will decrease the pollutants released into the atmosphere and water systems of the country.
5. Producing more rice will enhance the agronomic self-sufficiency of Indonesia, resulting in decreased food imports and a consequent saving of foreign exchange.

The results were presented at the Annual Review of the National Fertilizer Efficiency Program. The following strategy was proposed to implement the production of USG by briquetting at the dealer or village level.

1. Identify a potential company to fabricate the prototype briquetters. This company could be MIDC because it is a government-owned company that has a mandate to develop prototype machines and provide small-scale industry with the technical information necessary for fabricating equipment on a commercial basis. The prototype briquetters to be fabricated will be designed in a joint effort between MIDC and IFDC. This briquetter will incorporate the necessary modifications to improve its operation.
2. Identify the areas in which commercially produced USG would be used.
3. Identify the location where the first briquetters will be installed. The suggestion is to locate them at fertilizer dealers in order to benefit from immediate availability of urea and electricity and the interest of the dealer in promoting the use of USG.
4. Conduct USG production training programs for the potential dealers.
5. Determine the production capacity and operating range per briquetter after the use of USG increases. This would define how many briquetters are required in the future and where they should be located.

Ramon Lazo de la Vega, IFDC Special Project Engineer, and Encu Sumarta, MIDC Mechanical Engineer, observe the operation of the briquetter.

6. When additional information is obtained on the use and marketing of USG (3-5 years), perform a feasibility study including economic, marketing, and distribution aspects to determine the benefits of using a larger scale briquetter.
7. If the results from this study are encouraging, secure a commercially built pilot plant-scale briquetter to cover the market demand. This larger briquetter would provide the possibility of producing compound fertilizer with its extra capacity.
8. As this technology is adopted by farmers in Indonesia, begin to transfer the technology to neighboring countries.
9. To avoid duplication of efforts, conduct seminars and conferences (at least twice a year) in Indonesia and include participants from other countries.

If this technology can be successfully transferred to the farmer, the GOI will have found a way to successfully reduce the fertilizer subsidy with minimal impact on the profitability of using fertilizer by the farmer and with almost no negative impact on rice production. Work on finding ways to successfully transfer this technology will continue in 1988.

Building on the Latin American Foundation

Typical fertilizer transportation in the Antioquia-Andean Zone, Colombia.

The population of Latin America has been increasing at an average rate of 2.3%/year during the past decade. To meet the ever-increasing need for food, Latin American countries can resort to increasing productivity and/or to expanding croplands where available. Increases in productivity can be achieved through the use of agrochemicals and improved seeds, expansion of irrigated systems, and the adoption of improved cultural practices. Increases in total food production can also be achieved through the incorporation of new or marginal lands into the production process. In Latin America there are large areas of marginal low fertility lands that have agricultural potential. However, lack of appropriate infrastructure and high transportation costs to densely populated urban centers preclude their fast incorporation into the agricultural production process. Therefore, to meet the ever-increasing demand for food, increases in productivity along with a systematic incorporation of new or marginal lands are necessary. IFDC's efforts in research, technical assistance, and training are aimed at assisting Latin America in meeting its food requirements.

Research Activities

Nitrogen Research

Rhizobium/Fertilizer Research

Grain legume crops, such as chickpeas, pigeon peas, mung beans, common beans, lima beans, and soybeans, are important protein sources in many parts of the developing world. The yield of these crops are, however, generally quite low, usually averaging only about one-third of that of cereal crops grown under the same conditions. Due to their nutritional importance, increasing legume yields has been given a high priority in tropical

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During a UNDP Review of the Biological Nitrogen Fixation Project at Headquarters, Dr. Amit H. Roy (right), IFDC Special Project Engineer, explains the operation of the laboratory-scale granulation unit to (from left) Dr. Fernando Munevar, Dr. Gudni Hardarson, Dr. Lloyd Frederick, and Dr. Peter Graham.

agricultural research. Two important constraints to legume yields in the tropics have been identified as phosphorus and nitrogen nutrition. When the roots of legumes are associated with *Rhizobium* bacteria, they can fix nitrogen from the atmosphere, thus reducing the need for expensive chemical nitrogen fertilizers. However, for optimum nitrogen fixation to occur, adequate soil phosphorus and an efficient strain of *Rhizobium* must be present.

IFDC has been collaborating in a project entitled "Maximizing Crop Production Through Biological Nitrogen Fixation" with the International Center of Tropical Agriculture (CIAT), based in Cali, Colombia, and the Boyce Thompson Institute in the United States. This project is funded by UNDP. IFDC has concentrated its efforts on the development of a fertilizer-based inoculant that will deliver both an efficient *Rhizobium* strain and needed nutrients to the crop root zone. The use of conventional peat-based *Rhizobium* inoculants in the tropics has been slow to develop because suitable peat is rarely available in the tropics in economic quantities. Peat-based inoculants cannot stand desiccation or temperatures above 30°35°C, both of which can frequently occur in the agricultural inputs storage and distribution systems prevalent in tropical developing countries. The project objective is to develop an inoculant using as a carrier a fertilizer that is locally available, will provide needed nutrients, and will maintain viable *Rhizobium* under the storage and handling conditions found in the tropics.

In the first 2 years of the project, inoculants were made by spraying freeze-dried *Rhizobium* on a wide variety of fertilizer substrates using different granulation binding agents. In this, the third and final year of the project, significant improvements in the inoculant's quality were achieved using phosphate rock as a carrier and a new slurry production process. The initial *Rhizobium* population in these new inoculants consists of approximately 100 million/g of product. This compares very well with peat-based inoculants and, because the bacteria are freeze dried, they have much less sensitivity to high temperatures. Field tests of these new *Rhizobium* inoculant products are now needed to evaluate their agronomic performance.

Phosphate Research

Soil surveys conducted in tropical Latin America indicate that there are approximately 1.5 billion ha of arable land of which 1.2 billion or 82% of the total exhibit phosphorus deficiencies. These soils are generally characterized by their acidity and low fertility but which can be incorporated into the agricultural production process once the fertility limitations have been removed through the use of soil amendments and fertilizers with a high phosphorus content.

In Latin America, with the exception of Brazil, all countries depend to some degree on phosphate imports to supply their market needs. This is true even though a large number of countries have substantial phosphate rock reserves, which could be used to supply the need for phosphates. The development of phosphate reserves is especially attractive since it represents savings in foreign exchange through the reduction of phosphate imports and potential increases in food production due to an increased use of readily available fertilizers.

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For these reasons, during the past 10 years IFDC's phosphate project, based at CIAT in Colombia, has concentrated on phosphate research and technical assistance aimed at finding an effective means of using indigenous reserves of phosphate rock.

IFDC Headquarters' staff provide valuable backstopping to the phosphate field research. Here, Dr. Angel Calvo, Visiting Scientist, examines a greenhouse rice experiment.

CIAT-Based Colombian Research

The phosphate project conducted cooperatively with CIAT in Colombia and funded by IDRC has carried out a number of experiments in two agroclimatic zones of the Colombian Andes. These zones include the middle and high altitude tropics where, except for rice, most of the important phosphate-consuming crops, such as potatoes, sugarcane for "panela," beans, and maize, are grown. Most of the experiments were located on farmers' fields and conducted in collaboration with the Instituto Colombiano Agropecuario (ICA) Soils Program. Only a few pasture and potato experiments were located in ICA's Experiment Stations. Water requirements for experiments were provided exclusively by rainfall.

The two regions where experiments were established represent two agroclimatic zones typical of the Latin American midaltitude and the highland tropics. With some exceptions the soils are generally acid, low in available phosphorus, high in phosphorus-fixation capacity, high in aluminum saturation, and low in exchangeable calcium and magnesium. Soils that are high in available phosphorus are low in phosphorus-fixation capacity.

Objective—The objective of the last phase of the phosphate project was to identify the potential use of domestic phosphate reserves in Colombia. This study emphasized government policies that, if implemented, will promote the use of domestic phosphate rock reserves. Also, the study identified the conditions under which the development of the domestic reserves is a feasible alternative. These conditions relate to the fertilizer market, fertilizer supply, nature of phosphate reserves, and the availability of raw materials for the manufacture of fertilizers. The study was completed during 1987 and will serve as a model to conduct similar studies in other countries in the Andean zone and/or developing countries with phosphate reserves.

Agronomic and Economic Evaluation—Agronomic and economic evaluation of experiments performed to evaluate two methods of application with three phosphorus sources confirmed the results previously obtained. Higher yield increases, higher net returns, and higher agronomic efficiencies can be obtained with TSP and partially acidulated Huila phosphate rock point placed rather than broadcast. These two products have an overall performance much better than that of finely ground Huila phosphate rock.

A research worker harvests kingrass pasture from a phosphorus source experiment in ICA's El Nus Experiment Station, Antioquia, Colombia.

With respect to the time of application for the Huila phosphate rock, the agronomic response net returns and value:cost ratio were superior when the phosphate rock was applied broadcast and incorporated 30 days before planting. Applications of Huila phosphate rock 15 days before planting did not improve the agronomic effectiveness of the phosphate rock. Similar results were obtained with partially acidulated Huila phosphate rock when it was applied 30 days before planting. Applications of these materials 30 days before planting produced a good liming effect on acid soils with high aluminum saturation. TSP was most effective when applied at planting time.

Experiments on residual effects of Huila phosphate rock applied as an amendment indicate that for a second crop of beans this material produced the highest yield increase if compared to lime or to a mixture of lime and Huila phosphate rock. Economic evaluations of these experiments indicate that for the first planting TSP alone or applied with basal applications of Huila phosphate rock gave the highest yield increases, net returns, agronomic efficiency, and value:cost ratios. For the second planting the best economic results were obtained when TSP was reapplied over the previous application of lime as soil amendment. For soils with high phosphorus fixation capacity and low available phosphorus, Huila phosphate rock could probably be recommended not as a phosphate fertilizer but as an effective soil amendment. A mixture of Huila phosphate rock and dolomitic lime could be effective for soils with higher available phosphorus and high aluminum saturation. For soils having medium-to-low aluminum saturation (50%-10%) and relatively low phosphorus-fixation capacity, TSP applications without applications of soil amendments would be the best recommendation.

A worker harvests a sugarcane experiment in Antioquia, Colombia.

Agronomic and economic evaluation of experiments with beans and potatoes showed that mixtures with chicken manure or TSP gave consistently higher crop yields than mixtures of Huila phosphate rock with acidifying materials like ammonium sulfate or sulfur. Mixtures that contained ammonium sulfate as a source of nitrogen and sulfur were generally better than mixtures that used urea as the nitrogen source. Results of experiments with mixtures incubated anaerobically and nonincubated indicate that the incubation procedure used and the acidulating materials used to prepare Huila phosphate rock mixture did not seem to improve the agronomic efficiency of the phosphate rock.

Using mixtures of Huila phosphate rock with soluble phosphate fertilizers such as TSP, monoammonium phosphate (MAP), or DAP produced the highest value:cost ratios and yields of maize and beans similar to those produced by the same total amount of phosphorus using TSP alone.

During 1987 experiments with potatoes, beans, maize/bean, sugarcane, plantain, pasture grasses, and rice were established with the collaboration of ICA's Soil Program to compare and measure crop response to various phosphorus sources under different environments. In general, results of the economic

evaluation of the potato and bean experiments indicate that the application doses, net returns, yield increases, agronomic efficiency, and value:cost ratios for two partially acidulated rocks, Huila and Pesca, and for TSP were very similar and all superior to the untreated phosphate rock.

1987 Phosphate Network Activities

During 1987 IFDC, CIAT, and national research institutes or universities from Bolivia, Costa Rica, Colombia, Ecuador, Mexico, Peru, and Venezuela carried out a cooperative research project (Latin American Phosphate Network) to identify more effective sources of phosphate fertilizer for use on acid soils of tropical Latin America. Emphasis was given to management of phosphate fertilizers, especially methods and timing of application, use as soil amendments, and methods of acidulation and mixtures with organic and inorganic materials. These fertilizers were tested on potatoes, sugarcane, beans, and maize. The research was funded by IDRC of Canada.

Finely ground phosphate rocks from Colombia, Mexico, Peru, and Venezuela were found to be effective phosphate fertilizer sources on the acid Oxisols and Ultisols of the lowland tropics of Latin America. It was found that these phosphate rocks and others from Bolivia and Ecuador did not provide adequate quantities of soluble phosphate for cropping systems of the middle and high altitudes of the Andean region. However, experiments conducted in Bolivia and Peru showed that increasing the amount of water-soluble phosphate through the use of partially acidulated phosphate rock-based products can extend the use of indigenous phosphate rock to less acid or to neutral infertile soils. It has also been confirmed that in zones where direct application of finely ground phosphate rocks was not effective, a partial acidulation with sulfuric acid was necessary to achieve high yields, similar to those produced by conventionally produced soluble phosphate fertilizer applications. Preliminary economic studies indicate that production and use of phosphate rocks and PAPRs may provide a feasible alternative to importations of fully acidulated phosphates to the Andean countries.

Network Symposium on Latin American Phosphate Rocks—A symposium conducted during 1987 in Cali, Colombia, served as a forum for participants in the Latin American Phosphate Rock Network to summarize their findings on "Alternative Uses of Native Phosphates in Tropical and Subtropical America." The Network of Collaborators was formed as a part of a research project funded by IDRC, which concluded with the symposium hosted by CIAT.

Representatives were present from Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Peru, Mexico, and Venezuela to share their experiences concerning the use of natural and modified phosphate rock fertilizers in the wide range of soils and cropping systems encountered in Latin America. The event was also attended by approximately 100 research and fertilizer sector representatives.

A Colombian farmer helps harvest potatoes from phosphorus source experiments in Nariño.

Technical Assistance

Argentina

In mid-1987 GEASA, an Argentinian project development organization, initiated a fertilizer granulation plant project on behalf of a client in Paraguay. The proposed factory would produce DAP and a number of NPK products primarily for use in Paraguay. However, some product may also be supplied to other countries in the region in exchange for raw materials such as ammonia and phosphoric acid. The plant would have a nominal capacity of 100,000 mtpy. IFDC assisted GEASA in

obtaining proposals for engineering and equipment supply from a number of U.S. engineering and equipment firms. IFDC engineers reviewed the proposals, met with the prospective engineering firms to resolve/clarify technical questions, and recommended a course of action to GEASA.

Colombia

Instituto Colombiano Agropecuarios (ICA)

At the request of ICA of Colombia, IFDC collaborated with researchers from this institution in the development of a system to provide fertilizer recommendations for major food and cash crops.

The system is based on research results and soil-testing data obtained from experiments carried out in key agricultural areas and from soil results obtained through a regular service provided to the farmers by ICA laboratories.

The system is in the implementation stage. Computer programs have been developed that access experimental data and adjust values to provide a fertilizer recommendation for one specific area and crop. The system allows for updates and revisions of the recommendations, depending on ongoing research results. Complementary to the recommendation system, based on soil testing, guidelines have been given for the fertilizer use laboratory results, based on tissue analysis, for fertilizer recommendations in annual and perennial crops. Guidelines have been given on how to integrate into the system results of water analysis for irrigation purposes.

A data base management system has been designed that includes results from soil and fertilizer experimentation, fertilizer production, sources and blends available in the market, and prices of crop and fertilizer products. The system is still in the design stage.

Abonos Colombianos, S.A.

After considering several alternatives to revamp a nitrophosphate-based NPK plant to improve output, increase efficiency, and decrease pollution, Abonos Colombianos, S.A. (ABOCOL) decided to sponsor the required process research and development in pilot-plant scale at IFDC. The tests were designed to determine important parameters affecting operation of the wet section of the plant where N^{P} or NPK slurry is made for several different formulations. The data gathered were used to provide a basis for recommendations to ABOCOL for process and equipment modifications.

Ecuador

A company in Ecuador sponsored an IFDC engineer to inspect a fertilizer granulation plant in order to improve its cost effectiveness. The present operation is oriented to bulk blending of granular fertilizers based on imports. The study concluded that granular MAP could be produced in the plant in lieu of importing DAP, resulting in a substantial annual cost savings.

Venezuela

Fertilizer Blending Training Program

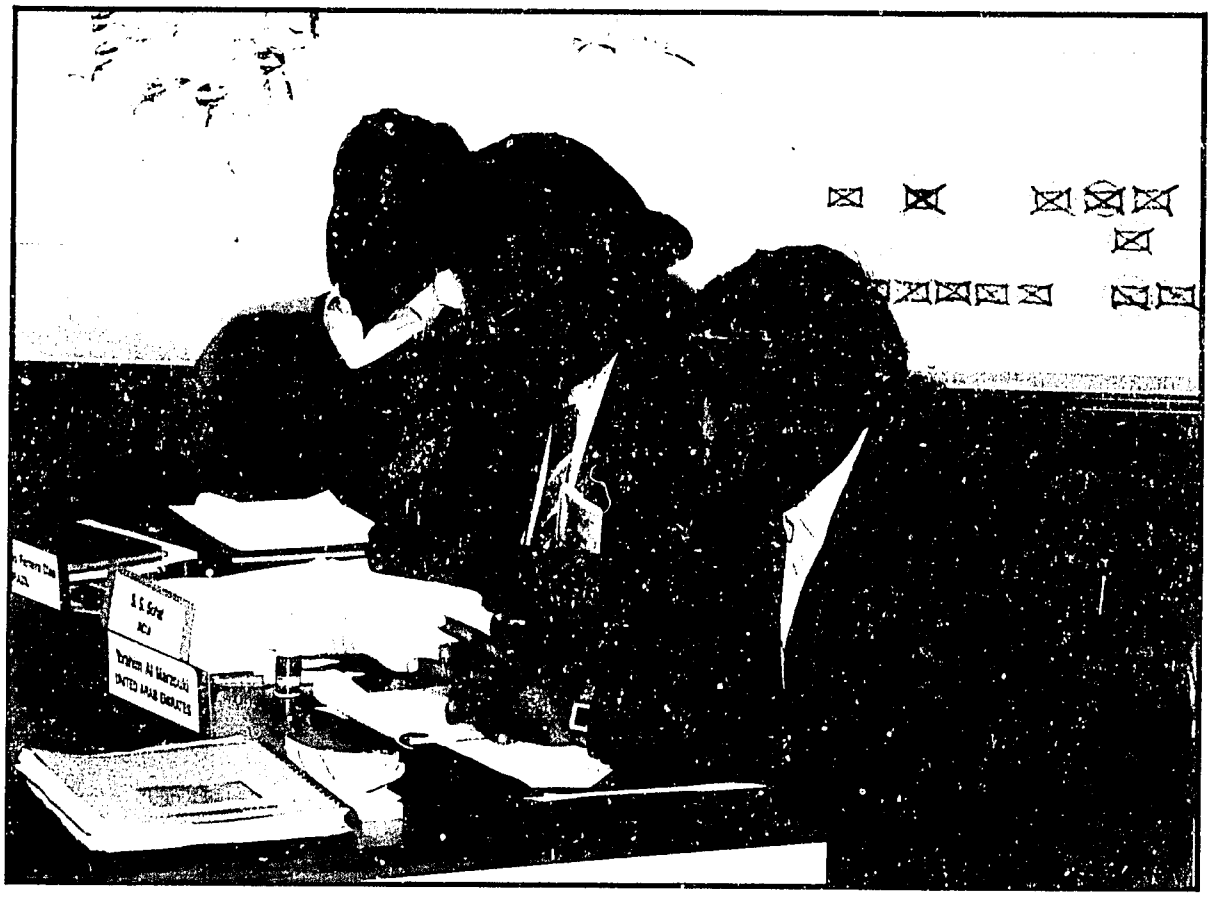
At the request of PALMAVEN, S.A., the marketing affiliate of Petroquimica de Venezuela, S.A. (PEQUIVEN), the fertilizer-producing subsidiary of Petroleos de Venezuela, S.A. (PDVSA), and the administrator of Venezuela's petroleum sector, IFDC conducted a fertilizer blending training program in Caracas, Venezuela, during 1987.

The main objectives of the program were to introduce participants to the production, marketing, and use of blended fertilizers; and to provide information for use in developing PALMAVEN's technical assistance and market development programs designed to prepare farmers for the blended NPK fertilizer that PEQUIVEN is planning to produce.

Blending Project

In addition to the training program, assistance was also provided to PEQUIVEN and PALMAVEN in evaluating the production, transportation, warehousing, handling, and distribution requirements for a major new blending facility. The PEQUIVEN proposal was for a sophisticated plant with automated handling facilities. As a result of this assistance, the project cost was significantly reduced.

Developing the Human Factor



Participants in the Fertilizer Maintenance Management and Production Technology Training Program work on a case study. They are (from left): Luis Eduardo Ferreire Dias (Brazil), S. S. Sohal (India), and Ibrahim Al Marzouka (United Arab Emirates).

The primary objective of IFDC's mission is to aid developing countries in increasing food production through the expanded and more efficient use of fertilizer. The achievement of this goal generally involves assisting these countries in overcoming those supply, marketing, and use constraints that limit the use of fertilizer by farmers. In many parts of the developing world the lack of sufficient numbers of skilled management and technical personnel poses a serious impediment to developing and transferring appropriate fertilizer technologies that will increase the cost-effectiveness and profitability of fertilizer use and thereby attract more farmers to its use. In many developing countries human resource development is hampered by shortages of people, facilities, and funds to train adequate numbers of managers and technicians to plan, organize, and operate the essential fertilizer production, marketing, and use research components of an effective fertilizer sector. Recognizing the severity and scope of the problem, IFDC—through a grant from UNDP—has made human resource development a principal and integral part of its overall fertilizer technology development and transfer program.

Since its establishment in 1974, IFDC has conducted 241 general and specialized training programs that have afforded knowledge-strengthening opportunities to over 3,200 individuals from over 100 countries spanning the globe. IFDC's training programs are directed toward building and strengthening the management and technical skills of developing-country personnel in a broad array of disciplines related to fertilizer production, marketing, and use efficiency research. Training programs are geared principally to enhancing the capabilities of junior- and middle-level managers and technical professionals who have demonstrated further career development

In many parts of the developing world the lack of sufficient numbers of skilled management and technical personnel poses a serious impediment to developing and transferring appropriate fertilizer technologies that will increase the cost-effectiveness and profitability of fertilizer use and thereby attract more farmers to its use.

Participants in the Fertilizer Marketing Management Training Program (from left: Iris Gonzales [Dominican Republic], R. Vijay Raghavan [India], and M. S. Venkataraman [India]) visit a farmer's field in Florida (U.S.A.).

Henry Ogola, Managing Director, MEA Ltd. (Cosponsor of the Regional Fertilizer Marketing Training Program), conducts participants of that program on a tour of the soils laboratory of the MEA fertilizer factory at Nakuru.

potential and more senior-level managers, planners, and administrators having decision-making roles in their organizations.

IFDC provides general (group) and specialized training programs tailored to serve the needs of individuals, public- and private-sector organizations, and development agencies engaged in fertilizer and agricultural sector development activities. General training takes the form of training programs, workshops, and seminars. These programs are conducted at IFDC Headquarters and/or at other U.S. locations and at conveniently accessible locations in Asia, Africa, and Latin America. The overseas programs are often cosponsored by and carried out in association with international, regional, and national organizations involved in fertilizer sector development. General training program faculties are drawn from the IFDC staff and increasingly from subject-matter specialists from developing countries. These account for over 30% of total program presentation time.

General training programs are structured to appeal to and meet the needs of broad segments of fertilizer-sector personnel engaged in various aspects of fertilizer production, marketing, and use efficiency research. Programs are open to all qualified applicants. They range in length from several days to up to 6 weeks; however, most are of 2- to 3-week duration. Training program methodology features presentations by subject-matter specialists and stresses active participant involvement in organized discussions, practical problem-solving exercises, and hands-on demonstrations to facilitate and enhance the learning experience. Field trips are generally an integral part of most training programs. They provide participants opportunities to observe the practical application of knowledge gained in the classroom and to expand on this knowledge base through first-hand discussions with personnel actively engaged in fertilizer production, marketing, and use research. Farm visits offer participants the chance to observe and discuss fertilizer use and application practices with farmers.

Participants' interests and training expectations are determined through discussions and completion of questionnaires. This information is essential in planning program curricula and implementation methodologies. Training

programs are evaluated by participants to further assist IFDC in planning new or revised programs to better meet participants' needs. Program content and training techniques are continually updated and upgraded to keep pace with the latest innovations in fertilizer sector development and operation.

In implementing training programs, IFDC employs advanced adult learning techniques, including computer-assisted simulation exercises, case studies, and role playing. Audiovisual components are featured to add clarity to and sustain interest in presentations and demonstrations. The manner in which the programs are organized and conducted encourages participants to exchange personal experiences and views within and outside the classroom on problems of mutual interest. In selected programs participants are tested at the beginning and conclusion of the program to determine the impact on the participants' knowledge level of the subject under study.

Specialized training programs are designed to meet the specific requirements of one or more individuals or organizations. These programs are usually conducted at IFDC Headquarters where specialized personnel and equipment are available, but they may also be carried out at other locations within or outside the United States as circumstances dictate. Specialized training programs may extend from several days to a year or longer and may cover topics related to virtually any aspect of fertilizer production, marketing, and use.

IFDC is fortunate in being able to draw on the support and cooperation of many organizations and individuals in carrying out its activities in human resource development. As noted earlier, various public- and private-sector organizations often cosponsor and work with IFDC in implementing regional and national training programs. Special recognition is due UNDP where funding support has enabled IFDC to expand the number, types, and frequency of training program offerings to better respond to the needs of fertilizer sector personnel in developing countries.

1987 Training Activities

During 1987 IFDC's training programs continued to be directed to improving fertilizer sector operations in developing countries by enhancing the technical and management expertise of additional numbers of individuals engaged in fertilizer production, marketing, and use efficiency research. In 1987 a combined total of 26 general and specialized training programs provided training to 229 middle- and senior-level administrators, managers, and technical professionals from 53 countries. Of that number, 170 participated in 10 general (group) training programs, and 59 took part in 16 specialized training programs.

General Training Programs

In 1987 IFDC conducted 10 general training programs. These are identified in Table 6. Five of the training programs were presented at IFDC Headquarters and included study tours to other U.S. locations. Five of the programs were held at locations outside the U.S.A.; two in Asia; and one each in Western Europe, Africa, and Latin America. With the exception of the training program conducted in Western Europe, all other overseas programs were cosponsored by national public- and private-sector organizations.

Participants in the Fertilizer Production Training Program tour a fertilizer plant in Malaysia.

In 1987 a combined total of 26 general and specialized training programs provided training to 229 middle- and senior-level administrators, managers, and technical professionals from 53 countries.

Table 6.
1987 IFDC General Training Programs

I. *Headquarters' Programs* (IFDC and other U.S. locations)
  A. *Fertilizer Production*
    1. Fertilizer Maintenance Management and Production Technology
  B. *Fertilizer Marketing*
    1. Fertilizer Marketing Management
  C. *Fertilizer Use Efficiency*
    1. Soil Testing and Fertility Management
    2. Statistical and Economic Analysis of Fertilizer Experimental Data
  D. *Fertilizer Sector*
    1. Data Collection, Analyses, and Projections for Fertilizer Sector Studies
II. *Overseas Programs*
  A. *Fertilizer Production*
    1. Fertilizer Production (Asia locations)
  B. *Fertilizer Marketing*
    1. Modern Techniques in Fertilizer Distribution and Handling (Western Europe locations)
    2. Fertilizer Marketing (Africa)
    3. Fertilizer Marketing (Asia)
  C. *Fertilizer Use Efficiency*
    1. Investigacion Sobre La Eficiencia de Fertilizantes en el Tropico (Cali, Colombia)

Of the 10 general training programs held in 1987, 2 related to fertilizer production, 4 to fertilizer marketing, and 3 to fertilizer use efficiency. One training program had broader fertilizer sector implications. The training programs on "Modern Techniques in Fertilizer Distribution and Handling" and "Statistical and Economic Analysis of Fertilizer Experimental Data" were new offerings in 1987. The training program, "Investigacion Sobre La Eficiencia de Fertilizantes en el Tropico," held at CIAT, was conducted in Spanish.

Participants in the Regional Fertilizer Marketing Training Program visit a coffee farm near Nairobi, Kenya.

The 10 general training programs attracted 170 individuals from 49 countries. Regional distribution of participants is shown in Table 7.

Table 7.
Regional Participation in 1987 General Training Programs

	Participants		Countries	
Region	Number	% of Total	Number	% of Total
Africa	58	34	18	37
Asia	72	43	16	33
South America	22	13	6	12
North/Central America	15	9	6	12
Europe	2	1	2	4
Oceania	1	-	1	2
Total	170	100	49	100

Asia with 43% had the highest representation, followed by Africa with 34%. Viewed from a country participation perspective, Africa has the highest representation with 18 countries, followed by Asia with 16 countries.

Specialized Training Programs

In 1987 specialized training was provided to 59 individuals from 13 countries. In all, 16 specialized training programs were conducted covering a wide range of topics related to fertilizer production, marketing, and use research. Specialized training programs are listed in Table 8; the number of participants, by country, involved in each training program is given.

Evaluation

Training program evaluation is an on-going process as IFDC seeks to improve current programs and to develop new programs and methodologies that will better reflect the participants' subject-matter needs and facilitate the learning process. This is accomplished through the use of formal program evaluation questionnaires and informal consultations with individual participants during and at the conclusion of each training program. These evaluation devices are intended to elicit participants' views as to the relevance and usefulness of program subject matter to their

Table 8.
1987 IFDC Specialized Training Programs

Training Program[a]	Participants		Program Length
	Country	Number	(days)
Fluid Fertilizers	Brazil	2	5
Drip Irrigation Technology U.S. Study Tour	P.R. of China	3	12
Phosphate Rock Mineralogy	P.R. of China	1	250
Fluid Fertilizers	Costa Rica	2	8
Manpower Planning and Project Management	India	3	10
Fertilizer Quality Control	India	1	15
Use of Microcomputers	Mali	1	15
Fertilizer Use Efficiency	Niger	1	5
Phosphate Fertilizer Technology	Poland	1	53
Irrigation Management Tour	Senegal	2	2
Phosphate Rock Cadmium Study	Togo	2	115
Phosphate Fertility Management	Uganda	1	5
Soil Fertility Research	Uganda	1	6
Fertilizer Blending—In Country	Venezuela	36	3
Fertilizer Production Quality Control	Yugoslavia	1	10
Soil Fertility Management	Zimbabwe	1	10
	13 Countries	59	

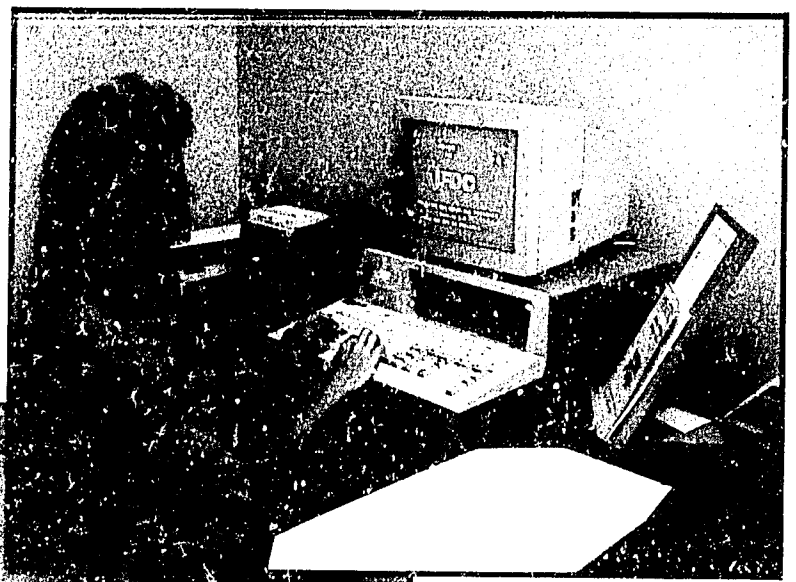
a. Programs conducted at IFDC except as otherwise indicated.

in-country work programs as well as the caliber of subject-matter presentation. Suggestions as to program improvements are, of course, also sought.

As indicated, participants' overall mean ratings ranged from a low of 3.75 (between "good" and "very good") for the "Fertilizer Maintenance Management and Production Technology Training Program" to a high of 4.59 (between "very good" and "excellent") for the "Data Collection, Analyses, and Projections for Fertilizer Sector Studies Training Program." With the exception noted above, all training programs received an overall rating of above 4.0.

As stated earlier, participant inputs are important guides to determining the types of training programs that are required, subject-matter emphasis and treatment, instructional methodology, course administration, and venue. In 1987 two new training programs were developed and offered in part in response to participants' expressions of the need for such programs. New 1987 training programs included (1) "Modern Techniques in Fertilizer Distribution and Handling" and (2) "Statistical and Economic Analysis of Fertilizer Experimental Data." As in 1986 greater use was made of guest lecturers from developing countries in 1987. In 1987 20 women, representing about 12% of the total number of participants, took part in IFDC's general training programs.

Extending Impact Through Special Global Projects



Sherry Bayless, Student Worker, enters information into the raw materials data base. This data base contains over 4,000 references on phosphate, sulfur, limestone, and nitrogen raw materials' resources in developing countries.

Linda Leagne, Computer Operator/Programmer, uses the VAX system to manage the fertilizer use efficiency database.

Agrominerals Databases

An ongoing activity is collection and entry of information into databases on fertilizer raw materials, intermediates, and production technology.

Two types of databases are being used. One is known as the "IFDC Raw Materials Database" and contains literature from published and unpublished sources indexed by subject matter. Initial emphasis is on phosphate technology that has been accumulated over a period of several years. Information is also included on nitrogen, potash, sulfur, and the geology of agronomical deposits. Due to current high interest in phosphate use, especially in developing countries in Africa, about 28% of the 1,900 records relate to developing countries in Africa and about 27% deal with other developing countries worldwide. This system is designed for use with an IBM PC or PC-compatible computer equipped with a hard disk and tape backup. Programming is in PASCAL language to reduce execution time and save storage space. This version is still developmental, even though programming is nearly complete. Literature entries are being accumulated and catalogued on a continuing basis.

A second database contains information on phosphate rock analyses. This database is stored on a dBase III+ file and can be searched, sorted, or printed using dBase III+ commands.

Fertilizer Use Efficiency Database Management

A specific approach in fertilizer use evaluation and efficiency testing has been the establishment and maintenance of a database 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 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 information gathered are depicted in Table 9.

Data from 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 Venezuela, Colombia, Uganda, Senegal, and Mali. 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 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 soil analysis calibration methods. Specific statistical and economic methods, using a multivariate technique, have been applied to evaluate a series of experiments conducted during several years in Mali, Niger, and Colombia.

Table 9.
Summary of Data Types in IFDC-Fertilizer Use and Efficiency Data Management System

	Data Type				
Countries	Predominant Ecosystems	Soil and Weather Factors	Fertilizer Nutrients	Cropping Systems	Crop Management
Colombia	Humid tropics	Soil classification	Nitrogen:	Rice	Cultivar
Ecuador	Semiarid tropics	Land capability	Urea	Maize	Planting date
Bolivia	Sahelian belt	Rainfall	Urea supergranule	Millet	Plant density
Costa Rica	Equatorial lowlands	Temperature	Calcium ammonium nitrate	Sorghum	Fertilizer applications
Mexico	Subhumid tropics	Solar radiation	Ammonium sulfate	Groundnuts	Crop protection
Nigeria	Tropical savanna	Soil moisture	Phosphorus:	Millet/cowpeas	Harvesting method
Senegal	Forest	Soil chemical analyses	Triple superphosphate	Beans	Crop factors:
Togo		Soil physical analyses	Simple superphosphate	Potatoes	Yield
Liberia			Phosphate rock	Cassava	Plant analysis
Cameroon			PAPR	Maize-cotton	Phenology
Sierra Leone			Sulfur	Maize-groundnut	
Gambia			Complex products		
Ghana					
Niger					
Kenya					
Burkina Faso					
India					
Bangladesh					
Syria					
Peru					
Venezuela					
Indonesia					
Philippines					
Guinée					
Benin					
Zimbabwe					

Crop Growth Simulation Modeling

The procedures for simulating soil and crop nitrogen dynamics were adapted from the CERES MAIZE into the new CERES SORGHUM and CERES MILLET models developed jointly by ICRISAT, the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), and Michigan State University. Modifications to the models to accommodate the effects of nitrogen deficit on tiller production and the development of a canopy were needed. New procedures for simulating the recovery of nitrogen from the vegetative part of the plant to grain were developed to allow differential rates of grain nitrogen accumulation across tillers. The two models are undergoing final development prior to testing.

In collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) and Michigan State University, work is proceeding on the development of the CERES BARLEY model. The IFDC nitrogen model has been incorporated into this model, and preliminary testing against data sets from Syria and Europe showed promising results. The model has many features in common with the CERES WHEAT model.

The CERES RICE model has also been the subject of ongoing development work. Modifications to the procedures developed for simulating recovery from transplanting shock have been made, and further refinements to the water balance components have been made. Preliminary procedures for simulating nitrification and denitrification and turnover of organic matter under flooded conditions have also been developed. Work is currently underway in assembling data sets for further development work and model validation.

For all the models IFDC has developed a comprehensive menu-driven user-friendly interface. This means that people with only very limited computer expertise can now run the models, change input conditions, and simulate many different scenarios. In collaboration with IBSNAT and the University of Florida, a graphics component has been added to the CERES WHEAT and CERES MAIZE models. The other models will receive this additional capability in the future.

Financial Report

Price Waterhouse

March 18, 1988

To the Board of Directors of
International Fertilizer Development Center

In our opinion, the accompanying balance sheets and the related statements of revenue and expenses and changes in fund balances, of functional expenses and of changes in cash and certificates of deposit present fairly the financial position of International Fertilizer Development Center (IFDC) at December 31, 1987 and 1986, and the results of its operations and changes in its fund balances for the years then ended, in conformity with generally accepted accounting principles consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Price Waterhouse

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

BALANCE SHEETS

ASSETS

CURRENT FUND

	December 31, 1987	December 31, 1986
Cash	$ 349,497	$ 134,800
Certificates of deposit	1,039,634	962,784
Amounts receivable from donors (Notes 1 and 2)	6,401,656	2,977,734
Other accounts receivable	699,246	1,160,366
Advances to employees	69,392	90,917
Supplies inventory (Note 1)	139,129	136,411
Prepaid expenses	182,665	140,696
	$8,881,219	$5,603,708

NONCURRENT FUND

	December 31, 1987	December 31, 1986
Amounts receivable from donors (Notes 1 and 2) - restricted	$2,345,804	$ -0-

BUILDINGS AND EQUIPMENT FUND

(Note 1)

	December 31, 1987	December 31, 1986
Buildings	$5,814,290	$5,814,290
Equipment	5,069,410	4,687,221
Less - Accumulated depreciation	(5,818,308)	(5,219,377)
	$5,065,392	$5,282,134

LIABILITIES AND FUND BALANCES

CURRENT FUND

	December 31, 1987	December 31, 1986
Accounts payable	$ 751,977	$ 258,684
Accrued annual and sick leave	1,533,808	1,439,808
Deferred revenue (Notes 1 and 2)	6,229,176	2,975,199
Total liabilities and deferred revenue	8,514,961	4,673,691
Fund balance	366,258	930,017
	$8,881,219	$5,603,708

NONCURRENT FUND

	December 31, 1987	December 31, 1986
Deferred revenue (Notes 1 and 2) - restricted	$2,345,804	$ -0-

BUILDINGS AND EQUIPMENT FUND

(Note 1)

	December 31, 1987	December 31, 1986
Contract retainage	$ 421	$ 421
Fund balance	5,064,971	5,281,713
	$5,065,392	$5,282,134

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF REVENUE AND EXPENSES AND CHANGES IN FUND BALANCES

FOR THE YEARS ENDED DECEMBER 31, 1987 AND 1986

	Current Fund		Buildings and Equipment Fund		Total All Funds	
	1987	1986	1987	1986	1987	1986
Revenue:						
Grants (Note 2)	$5,857,522	$5,903,352	$ 130,751		$5,988,273	$5,903,352
Recovered project costs	2,281,865	2,478,424			2,281,865	2,478,424
Other	88,028	139,154			88,028	139,154
Total revenue	8,227,415	8,520,930	130,751		8,358,166	8,520,930
Expenses:						
Field programs (Note 3)	1,072,946		27,709		1,100,655	
Research	3,320,344	3,523,058	434,864	$ 498,916	3,755,208	4,021,974
Outreach	2,407,941	2,165,872	47,008	56,740	2,454,949	2,222,612
General and administrative	1,734,135	1,760,395	93,720	95,432	1,827,855	1,855,827
Total expenses	8,535,366	7,449,325	603,301	651,088	9,138,667	8,100,413
Excess (deficiency) of revenue over expenses	(307,951)	1,071,605	(472,550)	(651,088)	($ 780,501)	$ 420,517
Other changes in fund balances:						
Capitalized lease	(30,089)		30,089			
Equipment acquisitions from unrestricted funds	(225,719)	(38,832)	225,719	38,832		
Fund balances, beginning of period	930,017	(102,756)	5,281,713	5,893,969		
Fund balances, end of period	$ 366,258	$ 930,017	$5,064,971	$5,281,713		

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

STATEMENTS OF FUNCTIONAL EXPENSES

FOR THE YEARS ENDED DECEMBER 31, 1987 AND 1986

	Field Programs (Note 3)	Research		Outreach		Administrative		Total Expenses	
	1987	1987	1986	1987	1986	1987	1986	1987	1986
Personnel compensation (Note 4)	$ 311,949	$1,819,862	$1,892,895	$ 993,718	$1,097,586	$ 970,637	$ 914,872	$4,096,166	$3,905,353
Personnel benefits (Note 4)	70,574	342,837	348,126	226,376	200,628	187,296	177,457	827,083	726,211
Travel and transportation	295,834	274,890	260,596	330,963	345,728	87,137	156,947	988,824	763,271
Occupancy	11,021	236,266	271,709	117,296	134,598	117,296	135,018	481,879	541,325
Telephone and telegraph	10,801	37,353	39,528	30,593	33,240	22,108	23,494	100,855	96,262
Rental of equipment	57,396	4,301	9,318	7,364	4,405	12,056	29,550	81,117	43,273
Contractual research and development	39,700	198,157	260,335	8,292	45,474	262	61,280	246,411	367,589
Other contractual services	91,852	187,925	187,899	268,475	163,867	67,985	72,126	616,237	423,892
Institute of International Education fee (Note 4)						134,414	120,930	134,414	120,930
Materials and supplies	164,939	158,846	194,648	376,019	97,142	105,840	40,890	805,644	332,680
Postage	3,743	19,335	20,893	18,580	20,256	8,962	9,525	50,620	50,674
Insurance	15,137	40,572	36,611	30,265	22,948	20,142	18,306	106,116	77,865
Miscellaneous			7,055		(1,989)	6,334	(3,176)	6,334	1,890
Total expenses before depreciation	1,072,946	3,320,344	3,530,113	2,407,941	2,163,883	1,740,469	1,757,219	8,541,700	7,451,215
Depreciation of buildings and equipment	27,709	434,864	491,861	47,008	58,729	87,386	98,608	596,967	649,198
Total expenses	$1,100,655	$3,755,208	$4,021,974	$2,454,949	$2,222,612	$1,827,855	$1,855,827	$9,138,667	$8,100,413

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER
STATEMENTS OF CHANGES IN CASH AND CERTIFICATES OF DEPOSIT

	Years ended December 31, 1987	1986
Balances at beginning of year:		
Cash	$ 134,800	$ 88,055
Certificates of deposit	962,784	217,939
	$1,097,584	$ 305,994
Cash was provided by:-		
Excess (deficiency) of revenue over expenses	($ 780,501)	$ 420,517
Charges (credits) not requiring (providing) cash:		
Depreciation	596,967	649,198
Revenue recognized on donated assets	(130,751)	
Capitalization of lease obligation	(30,089)	
Loss on disposal of equipment	6,334	1,890
Increase (decrease) in accrued annual and sick leave	94,001	(20,383)
Cash provided from operations	(244,039)	1,051,222
Net decrease in receivables from donors		723,605
Proceeds from sale of equipment		17,354
Net decrease in other accounts receivable	461,120	
Net increase in contract retainages		215
Net decrease in advances to employees	21,524	
Net decrease in supplies inventory		3,812
Net increase in accounts payable	493,293	9,046
Net increase in deferred revenue (current fund)	3,253,977	
	3,985,875	1,805,254
Cash was used for:		
Net increase in current amounts receivable from donors	3,423,922	
Net increase in advances to employees		22,222
Net increase in other accounts receivable		450,888
Net increase in supplies inventory	2,718	
Net increase in prepaid expenses	41,969	15,355
Net decrease in deferred revenue (current fund)		468,798
Purchase of buildings and equipment	225,719	56,401
	3,694,328	1,013,664
Net increase in cash	$ 291,547	$ 791,590
Balances at end of year:		
Cash	$ 349,497	$ 134,800
Certificates of deposit	1,039,634	962,784
	$1,389,131	$1,097,584

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.

NOTE 2 - GRANTS:-

Grants are summarized as follows:

	Years ended December 31,			
	1987		1986	
	Restricted	Unrestricted	Restricted	Unrestricted
Grants received -				
United States Agency for International Development (AID)	$2,430,934	$3,460,000		$4,000,000
United Nations Development Programme (UNDP)	3,130,000		$ 600,000	
Australian Development Assistance Bureau (ADAB)			65,000	153,318
International Development Research Centre (IDRC)	338,400			
Rockefeller Foundation			50,000	
Kellogg Foundation	1,462,500			
Israel Chemical Company				45,000
Directoraat Generalaal voor Internationale Samenwerking (Netherlands) (DGIS)	390,000			
World Bank	270,000			
Deutsche Gesellschaft fur Technische Zusammenarbeit		130,751		
	8,021,834	3,590,751	715,000	4,198,318
Amounts deferred during prior year	1,024,200	1,950,999	1,991,975	1,973,258
	9,046,034	5,541,750	2,706,975	6,171,576
Less - Amounts deferred to future periods	(6,948,938)	(1,626,042)	(1,024,200)	(1,950,999)
Other adjustments		(24,531)		
Revenue recognized in current period	$2,097,096	3,891,177	$1,682,775	4,220,577
		2,097,096		1,682,775
Total restricted and unrestricted		$5,988,273		$5,903,352

The unrestricted grants from AID provided funds of $3,460,000 and $4,000,000 during the fiscal years ending June 30, 1988 and 1987, respectively. The unrestricted ADAB grant in 1986 was a gift of funds recognized as revenue in the year received.

Restricted grants received were restricted by the grantor as to specific projects and/or geographic regions. The UNDP grant of $600,000 awarded during 1986 was restricted to use in research and outreach projects in East and Southeast Africa. This grant, originally due to expire in October, 1987, has been extended into 1988. Any grant funds not expended at the grant expiration date will revert to the grantor.

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. Two other grants received during 1987, $1,462,500 from the Kellogg Foundation and $390,000 from DGIS, were restricted to use in the development of the African Center in Togo.

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.

During 1987, IFDC received four restricted grants from AID. One grant for $224,434 concentrates on fertilizer research and training in Niger and expires 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. 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, 1987 and 1986 are summarized as follows:

	December 31,			
	1987		1986	
	Restricted	Unrestricted	Restricted	Unrestricted
AID	$2,300,762	$1,850,172	$ 57,576	$1,957,934
DGIS	390,000			
UNDP	2,956,267		628,367	
IDRC	266,690		288,257	
Kellogg Foundation	962,500			
Ford Foundation		21,069		45,600
	6,876,219	1,871,241	974,200	2,003,534
Less - noncurrent portion	2,345,804			
	$4,530,415	1,871,241	$ 974,200	2,003,534
		4,530,415		974,200
Total restricted and unrestricted		$6,401,656		$2,977,734

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.

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