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FERTILIZERS FOR TROPICAL AND SUBTROPICAL AGRICULTURE

by
Donald L. McCune

TWELFTH
FRANCIS NEW MEMORIAL
LECTURE

Presented before The Fertiliser Society of London
on 12th March, 1981

International Fertilizer Development Center

Abstract

Agriculture in the tropics and subtropics must become much more efficient and productive if the food, fiber, building materials, and energy needs of developing countries are to be met. Increasing amounts of the right kinds of fertilizers must be physically and economically available to farmers of these areas if their agricultural goals are to be attained.

Fertilizers and fertilizer practices that meet the specific needs of the tropics and subtropics must be tailored to the crop, soil, climate, and socioeconomic factors that prevail. With ever-increasing costs of raw materials, processing, and transportation, more attention must be given to the increased efficiency and recovery of applied nutrients.

The International Fertilizer Development Center (IFDC) was created in 1974 to develop new and improved fertilizers and fertilizer practices for developing countries with special emphasis on tropical and subtropical agriculture.

Nitrogen studies have focused on more efficient use of urea because urea is the main nitrogen fertilizer available to farmers in developing countries and often the only one. The efficiency of urea can be improved through deep placement in the soil, coating of urea granules to control the urea release rate, split applications, and improved management practices. Overall nitrogen efficiency can be improved by supplementing chemical nitrogen fertilizers with biological nitrogen fixation, recycling organic matter including green manures, and properly balancing nutrients.

Phosphorus deficiencies can be overcome through direct application of phosphate rock under certain conditions, use of partially acidulated phosphate rock, and greater use of thermophosphate in certain tropical areas. Greater use of indigenous resources must be encouraged.

Additional attention must be given to overcoming severe sulfur deficiencies and to providing a balance of nutrients through improved products and practices. More emphasis must be placed on identifying and correcting deficiencies of secondary elements and micronutrients in tropical agriculture. The fertilizer industry cannot serve tropical agriculture effectively by supplying primary nutrients only.

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FERTILIZERS FOR TROPICAL AND SUBTROPICAL AGRICULTURE

Introduction

It is indeed an honor to address this prestigious organization on the occasion of the 12th Francis New Memorial Lecture. I accept this honor as a tribute more to the organization that I represent than to me personally. I have had the opportunity of being with IFDC since its inception, some 6 years ago, and it has been the most rewarding experience of my career. Since the title of my lecture, "Fertilizers for Tropical and Subtropical Agriculture," is also a primary preoccupation of my organization, I think it appropriate that I address this subject in the context of what IFDC is and what we are doing in this area.

The International Fertilizer Development Center, better known as IFDC, is a nonprofit, public, international organization that was created in late 1974 to *develop new and improved fertilizers and fertilizer know-how for the developing countries with special emphasis on tropical and subtropical agriculture.* With the differences that exist in crops, soils, socioeconomic factors, and climates in the tropics and subtropics, the plant nutrient requirements for sustained, productive agriculture are certain to differ from the requirements for productive temperate-zone agriculture. The possibility for multiple cropping and even year-round agriculture wherever rainfall is adequate or irrigation potential exists will require not only additional major nutrients but no doubt a different approach to supplying the secondary and micronutrients.

IFDC was established primarily through the initiative of the U.S. Government by its Agency for International Development (USAID). The Canadian Government through its International Development Research Centre (IDRC) has also provided support since the inception of IFDC.

Dr. Henry Kissinger, then Secretary of State, provided the impetus for IFDC's creation in a speech before the United Nations (UN) General Assembly in 1974. Recognizing the role that fertilizers must play if the world is to be adequately fed, Dr. Kissinger urged "the establishment of international action on two specific areas of research: improving the effectiveness of chemical fertilizers, especially in tropical agriculture, and new methods to produce fertilizers from nonpetroleum resources." Dr. Kissinger further stated, "The United States will contribute facilities, technology, and expertise to such an undertaking."

In October 1974 IFDC was created as a nonprofit corporation under the laws of the State of Alabama. Once created, IFDC immediately took steps to qualify as an international organization under the laws of the U.S. Government. By early 1977 these qualifications had been met, and in March 1977 President Carter signed a decree giving IFDC international status and all the privileges and immunities associated with this designation. IFDC became an organization with status similar to that enjoyed by the World Bank, regional banks, and UN organizations located in the United States.

The Alabama location was selected so that IFDC could take advantage of U.S. expertise and facilities located at the Tennessee Valley Authority's (TVA) National Fertilizer Development Center at Muscle Shoals. Locating IFDC Headquarters on a 30-acre tract of TVA land has proven beneficial to IFDC and, hopefully, to TVA. Even though IFDC and TVA are two distinct and separate organizations, the advantages of close proximity are many. We do share certain facilities, such as a technical library and a medical center, on a reimbursable basis. TVA furnishes security, fire protection, grounds maintenance, some utilities, and fertilizer raw materials and intermediates on a cost basis to IFDC. This was a great advantage in both initial cost and rapidity of establishment.

USAID furnished funding for IFDC's buildings and for major capital equipment purchases. USAID is also our major donor and will furnish about one-half of the operating funds for our 1981 budget of slightly over $8 million. Canada, through IDRC, continues to fund certain portions of our phosphate research. The United Nations Development Programme (UNDP) has become a major funding organization, especially in our training efforts. Australia is funding a sizable portion of our nitrogen work, and both Israel and the Philippines have made annual contributions to our core budgets. About 30% of our work is aimed toward special projects for individual countries. This work is funded either by the recipient country or by donor organizations that have bilateral interests in these countries.

One qualification for international status was that IFDC have an international Board of Directors. Our Board is made up of 12 members: three from the United States, three from other developed nations, and six representing the various regions of the developing world. The Board serves staggered 3-year terms and regenerates

itself each year. Board members serve in individual capacities and do not represent governments or organizations. The normal tenure for Board members will probably be no more than two 3-year terms. Dr. George W. Cooke of the United Kingdom did serve on our Board but now assists IFDC in an advisory capacity.

IFDC's core staff at the professional level numbers approximately 60 and is internationally recruited. While most of our staff is located at Headquarters, we presently have seven positions in four developing countries, and we expect this number to grow. Our international status makes international recruitment much easier. International staff members hold diplomatic visas and the privileges and immunities associated with this status. International status also encourages a broader funding base due to the preferred international organization tax status.

IFDC is organized into three divisions—Agro-Economic, Outreach, and Fertilizer Technology; however, much of our work is carried out by interdisciplinary task teams. These task teams are composed of highly qualified IFDC staff: agronomists, soil scientists, social scientists, statisticians, plant physiologists, microbiologists, economists, training and communications specialists, editors, engineers, geologists, chemists, etc. We also make liberal use of consultants if other disciplines or additional help is needed.

Our *modus operandi* in program planning is to clearly identify fertilizer needs. Our staff members work with selected specialists in a given field including scientists and engineers from both developed and developing countries. We look first for solutions by adopting or adapting existing fertilizers, processes, or knowledge from anywhere in the world. If further work is indicated, we assign the involved disciplines to task teams for planning and conducting the work.

Even though we are proponents of balanced fertilization, we decided that our first efforts should be on nitrogen and phosphorus to improve their efficiency and to make more extensive use of indigenous resources. In nitrogen research we concentrated first on the fertilization of rice, primarily in Asia. In 1980 we initiated a nitrogen efficiency program for upland crops. Phosphate work was first directed to the vast areas of low phosphate soils in South America. In 1981 we will expand this work to west Africa and will give special attention to the landlocked countries of the Sahel region by trying to identify solutions to their critical phosphate problems based on their small but adequate indigenous phosphate deposits.

With the assistance of the Australians and The Sulphur Institute, we are now outlining programs on sulfur research and development to determine what IFDC can and should do to resolve the problems that are identified. We are thoroughly convinced that sulfur is so important in the tropics that, contrary to developed country practice, it must be treated as a major nutrient in the tailoring of fertilizers for tropical and subtropical agriculture.

In the next few years, in cooperation with the International Potash Institute (IPI) and the Potash and Phosphate Institute (PPI), we hope to develop a status paper on potash and to study, to some extent, calcium and magnesium. Again, the goal is to guide IFDC in determining what research and development it should be involved in regarding these elements as plant nutrients.

Although we see evidence that the minor nutrient requirements are greater in sustained, highly productive agriculture in the tropics than in temperate-zone agriculture, time and budget have not permitted us to consider seriously what role IFDC can play. To date and for the foreseeable future, IFDC will have to provide assistance on micronutrients based only on the scarce existing knowledge pertaining to the tropics and subtropics.

The Problem

Foremost in our minds must be concern for what I feel is the most urgent problem facing the world for the remainder of this century and into the 21st century. That problem is how to feed, clothe, and shelter an ever-expanding world population in a manner commensurate with the desire for improved living standards.

Population continues to expand (Figure 1).[1] Within my lifetime population has more than doubled and will exceed 6 billion people by the year 2000. Even though great efforts, and some success, have been experienced in birth control programs, equally and oftentimes more successful programs in medicine and public health have either eliminated or greatly reduced the prevalence of diseases that once were effective in keeping population in check. Life expectancy is increasing rapidly. Today, life expectancy at birth for low-income countries has increased from 35 years in 1950 to 50 years in 1978.[2]

With energy prices continuing to spiral upward, agriculture must also be intensified to produce additional materials for fiber, construction, and energy (methane, alcohol, biomass) which were once made

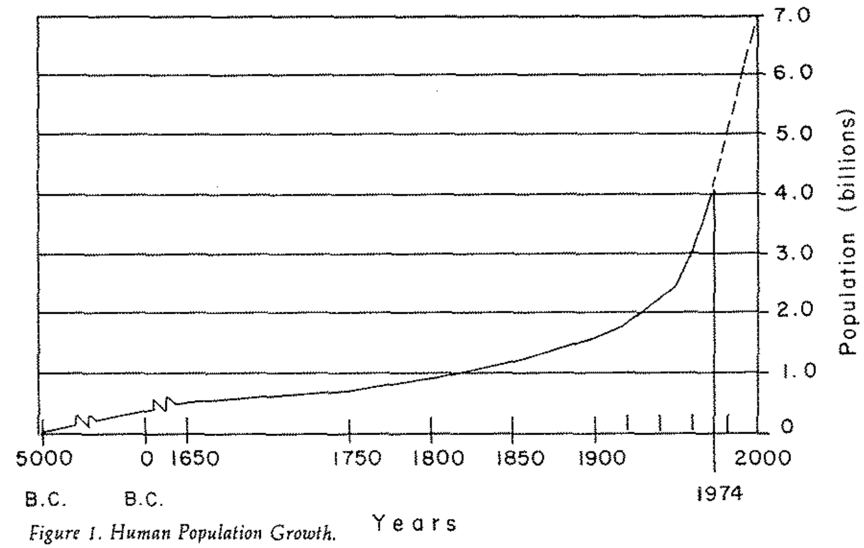


Figure 1. Human Population Growth.

from petroleum when prices were favorable.

Thus, agriculture must become much more intensive and productive. Much of this increase must be accomplished in the tropics and subtropics where most of the new demand is anticipated.

Agricultural Production Potential in the Tropics

Fortunately, there still remains much potential for increasing agricultural production. This is especially true in the tropics where the need for food is the greatest and this need is expanding the most rapidly. The U.S. President's Science Advisory Committee in the late 1960s estimated that there are at least 4 billion ha of potentially arable land and an equal amount of potentially grazable land within the tropics.[3] This is half of the total agricultural land resource of the world. Present production falls far short of this potential and need.

Even though some additional land will be brought into production, this will not occur rapidly enough to keep up with the increasing demand for agricultural production. Mr. Robert McNamara, President of the World Bank, recently stated that no more than a 1% per year increase in new agricultural land could be expected worldwide.[4] Thus, increased agricultural production will have to be accomplished primarily by increasing the yields on land already under cultivation. Increasing the acreage and, even more importantly, increasing the yield of existing land will require large quantities of fertilizer. These increased quantities will be used only if the fertilizers are effective and thus economical for the farmer.

Several types of tropical agriculture could be defined that differ according to climate, soil characteristics, and management. One type is found in areas such as Southeast Asia where relatively fertile soils have been farmed for centuries. By careful conservation of soil fertility and recycling of organic matter, a low but stable yield has been maintained. This type of agriculture includes some of the most densely populated areas in the world (e.g., Java). As the population increases, these people must turn to increased fertilizer use and more intensive agricultural practices such as multiple cropping.

In other, less heavily populated areas, shifting cultivation, including various systems of slash and burn, has been practiced as the best alternative. Land cleared and brought under cultivation produces satisfactory crops for only a few years. This system has been adequate for low, primarily rural population densities. With increasing population pressure and urban growth, these traditional practices must be replaced with more productive permanent cropping systems.

Finally, there are large areas of "new" land, particularly in tropical areas of South America, where the soil is well watered and structurally suitable for agriculture, but the native fertility is too low even for shifting agriculture. These soils are capable of good crop yields when properly fertilized, and eventually their output will be needed.

The Role of Fertilizers

The role that fertilizers can and must play in improving agricultural production in the developing countries is becoming widely recognized. Fortunately, this recognition is no longer limited to those involved in fertilizers.

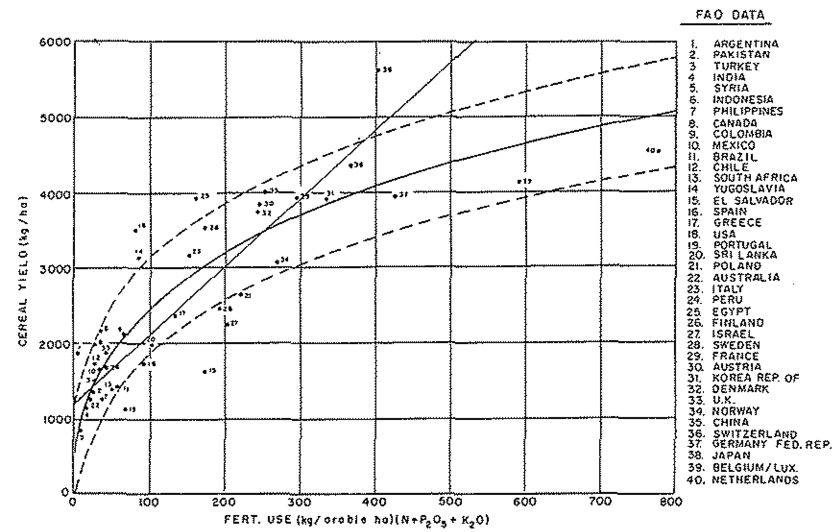
The International Rice Research Institute (IRRI) has evaluated the factors that have gone into increasing rice yields in Asia during what has become known as "The Green Revolution." They have shown that fertilizers have accounted for at least 50% of the yield increase.[5] They have further shown that, compared with other inputs, fertilizer was consistently the best buy in their analysis.

Wheat is another important crop that contributed to the Green Revolution's success. Dr. Norman Borlaug, Wheat Breeder of the

International Maize and Wheat Improvement Center (CIMMYT) and recipient of the Nobel Peace Prize in 1970, has stated, "If high-yielding varieties are the catalyst, fertilizer is the fuel for the green revolution."

Others, including Dr. Saburo Okita, formerly Managing Director, International Development Center of Japan, have pointed out that the secret to success in tropical agriculture is making full use of water and fertilizers.[6]

Another interesting piece of work by Williams and Couston of the Food and Agriculture Organization of the United Nations (FAO) in the early 1960s showed that fertilizer use in some 40 countries was highly correlated with grain yields. They found no other input that had nearly as good a correlation. Figure 2 is an updated chart showing this correlation for the years 1972-76.[7] Unfortunately, most of the developing countries are still clustered in the lower left corner of the chart where both yields and fertilizer use are low. South Korea and



Source: Private Communication From J. W. Couston.

Figure 2. National Use of Fertilizer and Grain Yields, 40 Countries, 1972-76.

Egypt are exceptions. The fertilizer use rate per arable hectare reported for the Netherlands and Belgium is fictitiously high because these countries use heavy fertilizer application on grassland. When these points are omitted, the remaining points are adequately represented by the straight line whose slope is 9.1169F which is equal to 9.1 kg of cereal/kg of plant nutrient.[8]

For several years FAO has placed major emphasis on testing and demonstrating conventional fertilizers on thousands of farms throughout the developing world. The fertilizer industry, especially of Europe, has also joined with FAO in supporting this work. These activities, formalized under the Fertilizer Industry Advisory Committee (FIAC), encouraged industry to contribute funds and fertilizers that have permitted FAO to expand greatly its programs and to acquaint thousands of farmers with existing fertilizers and the results of their use. In recent years, governments, again primarily European, have contributed funds and personnel to this worthy endeavor.

Fertilizer Use

Like population, fertilizer use has been increasing rapidly (Figure 3).[9] Starting with less than 2 million tons of N, P_2O_5, and K_2O in 1905, growth was relatively slow at first with setbacks caused by world wars

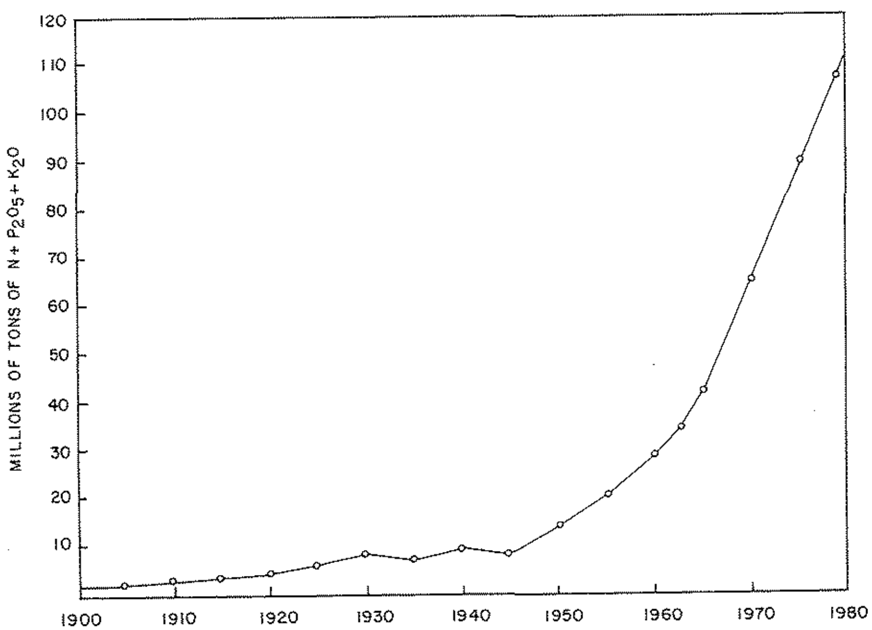


Figure 3. World Fertilizer Use.

and a worldwide depression. After the Second World War growth accelerated from about 14 million tons in 1950 to about 107 in 1979. The United Nations Industrial Development Organization (UNIDO) has projected that total fertilizer use by the year 2000 would approach 290 million tons of nutrients as shown in Figure 4.[10] Experience over the past few years would indicate that this level may well be reached.

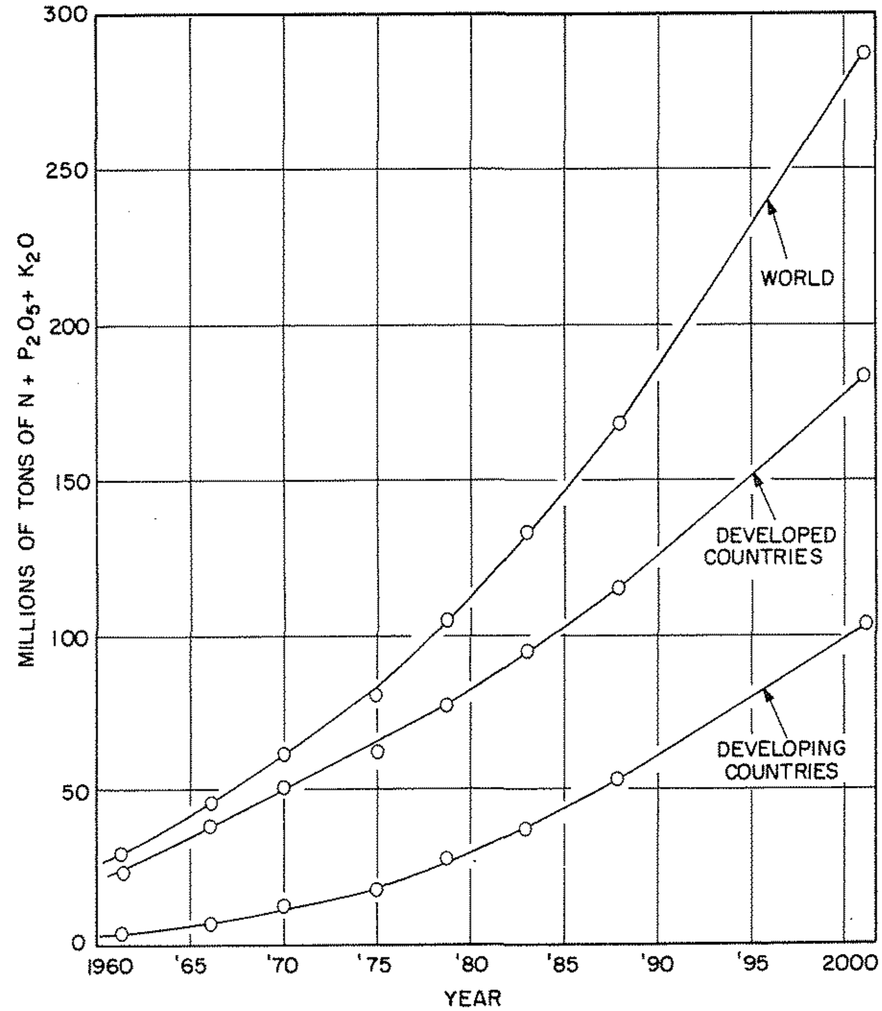


Figure 4. World Fertilizer Use: Projections by UNIDO.

Fertilizer use in the developing countries has been increasing more rapidly than in the more mature markets of the developed world. In 1969 developing countries accounted for 18% of total world plant nutrient use, whereas their use increased to over 27% 10 years later (1979) and is expected to reach 29% by 1985.[11]

Fertilizer prices were very volatile during the decade of the 1970s.[11] Figure 5 shows export prices of selected fertilizers for the period 1968-80.[12] Although prices fell after reaching all-time highs in 1975, the overall trend is one of increasing prices. This increase is due primarily to rapidly rising energy prices and their effect on fertilizer production and transport costs.

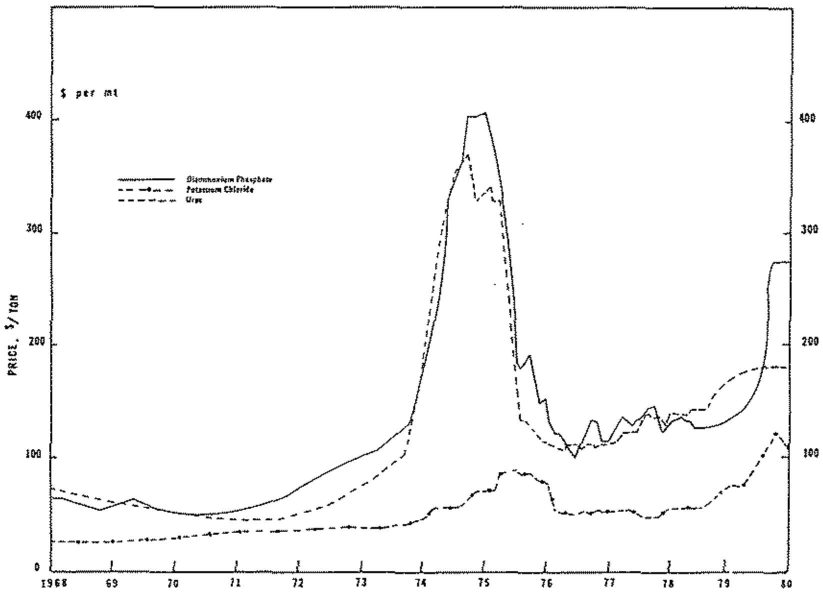


Figure 5. Export Prices of Selected Fertilizers, 1968-80.

Fertilizer Use Efficiency

Prior to the sharp price increases experienced in the mid-1970s, fertilizer prices were so low that little attention was paid to fertilizer-use efficiency. Biological fixation of nitrogen and the use of legumes in the rotation had essentially been ignored; organic wastes were viewed as a disposal problem and not as a valuable and renewable resource of plant nutrients; the growing of green manures had been largely

abandoned as a practice; and interest in cheaper sources of nutrients such as the direct application of rock phosphates had waned. With the rapid increase in fertilizer prices, interest in all of these practices has been renewed.

Petroleum prices have increased more than tenfold and have caused fertilizer production and transport prices to increase accordingly. This is especially true for nitrogen. The Fertilizer Institute (TFI), in a recent survey of U.S. fertilizer producers, has shown that the manufacture of 1 ton of nitrogen in the form of urea consumes from 75 to 80 gigajoules (GJ) of energy.[13] T. P. Hignett has calculated that if one includes the energy that is required for the manufacturing of polyethylene bags and transportation to farmers, the total energy required to produce a 50-kg bag of urea would be roughly equivalent to 38 liters (10 U.S. gallons) of gasoline.[14] This calculation underlines the importance of using nitrogen fertilizers efficiently. Hignett has shown the dependence of the production of various fertilizers on energy.[14] He reports that if the developing countries as a whole continue to use the primary fertilizer elements, N, P_2O_5, and K_2O, in the ratio of 4:2:1, then 92.4% of the total energy used for manufacturing these fertilizers will be for nitrogen, 6.1% for phosphorus, and 1.5% for potash.

For fertilizers to perform efficiently in a given climate and soil, all other production factors must be in balance. This, of course, includes adequate moisture, the right crop and variety, adequate weed and pest control, good cultural practices, etc. Efficient production also requires balanced fertility. For example, in a "missing element" experiment (Figure 6) conducted in Colombia, it was shown that the most limiting elements in this soil were sulfur, boron, calcium, and phosphorus—only one of which is a major element.[15] Thus, it is evident that to obtain an economical and efficient response to the other so-called major elements, N and K, the deficiencies of at least these four most limiting elements would have to be corrected. This and other similar evidence give a strong indication that the conventional primary nutrient (N, P, and K) approach to fertilizers may not be adequate in tropical agriculture.

Of the so-called primary nutrients (N, P, and K), nitrogen is not only the most dependent on energy costs, it is also the most subject to losses. Seldom more than half of the applied nitrogen is recovered by crops, and often in the developing countries 30% or less may be recovered. Thus, opportunities for increasing the efficiency of nitrogen are great.

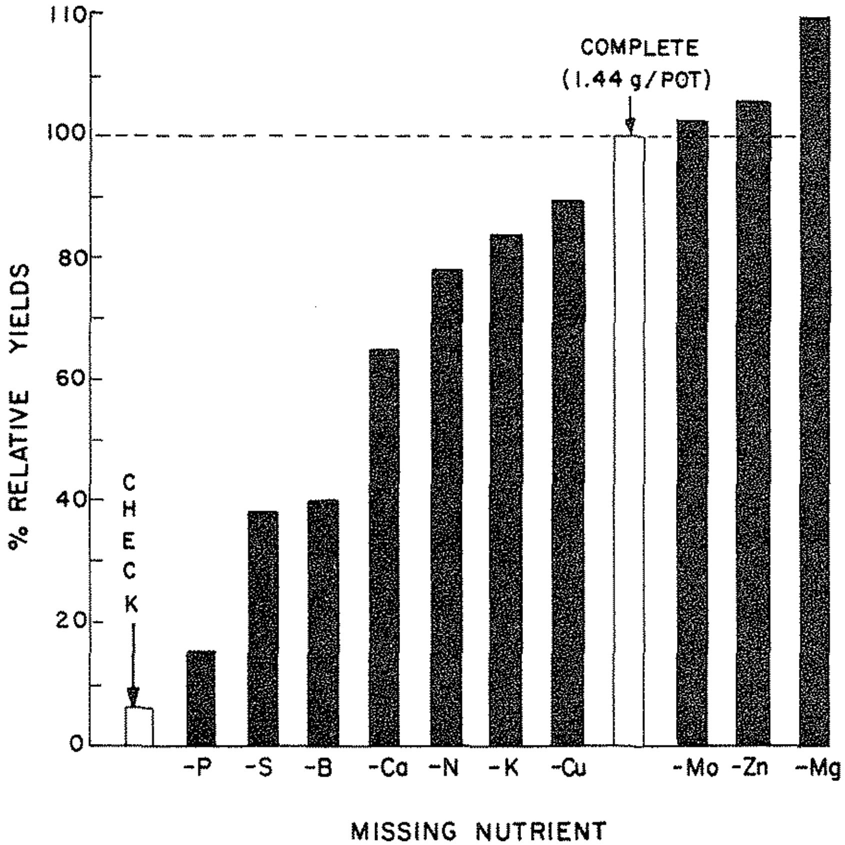


Figure 6. Effect of Missing Nutrient on Yields in a Tropical South American Soil.

Even though nitrogen can be produced in the form of ammonium sulfate, ammonium nitrate, ammonium chloride, and urea, the new production in the developing world is based almost entirely on urea. Although, from an agronomic viewpoint, other sources may be superior to urea, most farmers in the developing world will have only urea available to them. This swing is due to the fact that urea can usually be delivered to the farmer at less cost per unit of N than any other form. Thus, improving nitrogen efficiency in the developing world means improving the efficiency of urea.

To improve the efficiency of urea, probably the first action should be to use other nutrients at near optimum levels. This includes not only P and K but also S, Ca, and Mg, as well as zinc and other micronutrients that may be limiting. Since these other elements are less energy dependent, they should not rise in price as rapidly as nitrogen. If other nutrients are at or near optimum, nitrogen fertilizer should perform more efficiently.

At IFDC, other than attempting to ensure that other nutrients are available in adequate quantities, our approach has been to study the methods and magnitude of nitrogen loss and to then tailor management practices and alter urea to combat these losses. We feel that if we can keep the urea or its reaction products within the root zone until roots permeate this zone, plants will be able to make better use of this applied nitrogen.

In rice culture we have convincingly shown that a major loss mechanism is volatilization of ammonia from the floodwater. If we can keep the ammonia levels in the floodwater low, we can greatly slow down volatilization. Also, if the nitrogen levels in the floodwater can be kept low, blue-green algae strains that fix nitrogen can be encouraged. Under some conditions these free-living algae can add 30-50 kg/ha of additional nitrogen to paddy rice.

We have tried several approaches to maintaining a low ammonia level in the flood water: the use of urease inhibitors, coating of the urea granules to control the release of urea, and deep placement of the urea into the soil. All approaches have met with some success. Urease inhibitors have been less successful, and the use of coatings (sulfur coatings or others) is costly. Deep placement has been the most promising.

With proper deep placement within the reduced zone of puddled soils, we have consistently shown that the efficiency of urea can at least be doubled. The problem becomes one of determining how materials can easily be placed in small paddies.

Originally the Japanese, and later the Chinese, developed the "mudball technique." A mudball about 5-8 cm in diameter is formed by hand; a pocket is formed by inserting the thumb; and the pocket is filled with fertilizer and then closed with more mud (Figure 7).[16] The mudballs are allowed to dry, and they are inserted into the rice paddy manually. Usually one mudball supplies fertilizer for four rice hills (Figure 8).[16] Mudballs are quite effective in reducing losses and consequently increasing rice yields or reducing urea requirements. However, since about 62,500 mudballs are needed for 1 ha, the procedure is highly labor intensive. Even where labor is plentiful and cheap, this practice has not become popular.

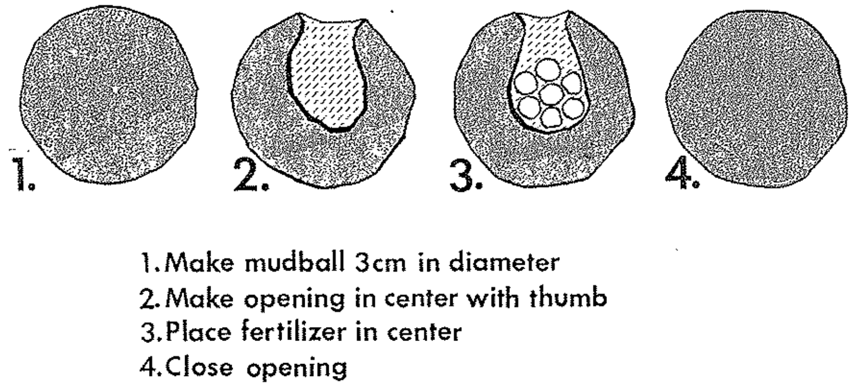


Figure 7. Placing Fertilizer in Mudball.

IFDC has taken the lead in producing or supplying "supergranules" as either granules or briquettes of 1-, 2-, or 3-g size which can be placed manually like mudballs.

The deep-placed supergranules or briquettes were quite effective in decreasing losses and increasing yields. In one group of tests, the apparent nitrogen recovery from deep-placed supergranules was about 80%; whereas, the recovery from surface-applied prilled urea (split application) was only 30%.[17] The increase in yield from the deep-placed granules was double that of surface-applied prills.

In some countries, such as South Korea where the average application rate is already high, improved efficiency can be used to decrease the quantity of urea. For example, in some tests the same yield has been obtained with half as much deep-placed urea as compared with surface application.

Although deep placement of large granules has been proven to be an effective way to increase the efficiency of urea nitrogen use and is much less labor intensive than the mudball technique, it is still labor intensive when the granules are manually placed. The Chinese have developed a simple, manually operated machine for deep placement of supergranules or briquettes which makes the job easier and quicker. Even so, any change in management practices of hundreds of millions of small farmers will be a difficult, time-consuming job.

IFDC has also supplied slow-release nitrogen fertilizers such as sulfur-coated urea (SCU) for tests in cooperation with IRRI and other agencies. We have been particularly interested in large SCU, such as forestry grade (about 4-6 mm). The larger granules require less sulfur and contain more N than the conventional-size granules.

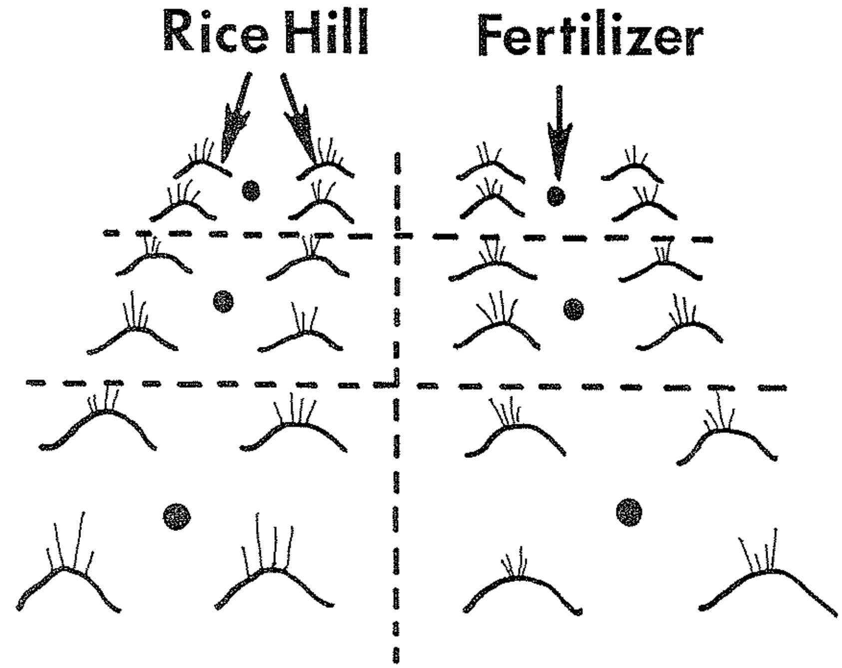


Figure 8. Fertilizer Placement in Rice Paddy.

As compared with deep placement of large, uncoated urea granules, SCU has the following advantages:

1. There is no need to change farmers' practices; SCU can be broadcast in the floodwater which is the usual practice. No increase in farm labor or equipment cost is required.
2. SCU supplies sulfur which is often deficient in developing countries.
3. SCU is less affected by exposure to humid atmosphere.

The disadvantages of SCU are the following:

1. Higher cost.
2. Limited commercial availability.
3. Reduction in the rate of biological fixation of N. This reduction is not as drastic as that of prilled urea when both are broadcast and incorporated.[18]

Recent increases in the cost of sulfur have caused a loss of interest in SCU. However, large new supplies of sulfur are expected to come on the market from conversion of coal to liquid and gaseous fuels and from other byproduct sources. A surplus supply of sulfur has been predicted that would result in a decrease in price.[19] Thus, we think it worthwhile to continue tests to evaluate SCU.

IFDC and IRRI have jointly sponsored an International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) in which 11 countries (later expanded to 15) cooperated to test various new fertilizer materials and application methods. An average of 94 tests gave the following results.[17]

Type of Urea Application	Yield Increase kg of Rice/kg N
Prilled, best split	16.6
Mudball, deep placement	23.0
Supergranule, deep placement	21.1
SCU, broadcast and incorporated	23.6

The test results showed considerable variation from one location to another in relative advantages of SCU and deep placement; the cause of these variations is being studied.

The "best split" is a practice recommended to farmers but seldom used by them. It consists of broadcasting and incorporating (by harrowing) one-half to two-thirds of the nitrogen at the time of transplanting, and broadcasting the remainder in the floodwater when the rice plant begins to form heads. Farmers' practices usually consist of broadcasting the fertilizer directly into the floodwater after transplanting, either as a single or split application. Also, the test results shown above were conducted with good water control which eliminates or minimizes losses by runoff and by nitrification-denitrification. Only about 30% of the rice-farming area has good water control. For these reasons results actually obtained by farmers are likely to be poorer and, hence, susceptible to greater improvement than the above data indicate.

Phosphate Fertilizers

Phosphate appears to be the second most important nutrient in tropical and subtropical agriculture. In certain areas it is so deficient that limited response to nitrogen or other elements can be expected unless the phosphorus deficiency is corrected.

As late as 8 years ago phosphate rock was available at the mine at a price comparable to that of washed sand or gravel. Prices at Florida mines had been about $5/$7/ton for many years.[20] Prices, f.o.b. Florida and Morocco ports, were about $10/ton, and delivered prices in many of the world's ports did not exceed $20. Under these conditions, prospecting for new deposits was hardly worthwhile, and development of new deposits was not attractive if there were any problems involved.

The sudden shortage and abrupt price increases of 1974/75 brought a renewed interest in finding and utilizing indigenous phosphate rock deposits in developing countries. Although prices of commercial phosphate rock soon receded from the peaks of 1975, they are increasing again under inflationary pressures and are now in the vicinity of $40/ton for 70%-72% BPL rock, f.o.b. exporting port.[21] Mining and beneficiation of phosphate rock are not particularly energy intensive, but the prospect is that costs and prices will continue to increase and the average grade of phosphate rock will continue to fall.

The cost of transporting phosphate rock is directly related to energy costs, and freight costs often exceed the f.o.b. cost of the cargo. In 1979, 52 million tons of phosphate rock moved in seaborne trade, about 41% of the total production of 128 million tons.[22] The equivalent of another 20 million tons of phosphate rock moved in international trade as finished fertilizers or phosphatic intermediates. Many developing countries must import either phosphate rock or processed phosphates, often from a great distance. Although further exploration is needed, many developing countries are known to have indigenous deposits of phosphate rock which are not now being used. Often the local deposits are not well suited to conventional processing because of low grade or impurities such as carbonates, chlorides, or excessive silica. Thus, a part of IFDC's phosphate program is concerned with helping developing countries use their indigenous phosphate deposits economically either by beneficiation or by processing them in unconventional ways or by direct application. Much of this work is carried out by special projects; each project is related to a single phosphate deposit in a specific country.

In a broader context, IFDC is interested in finding the most cost-effective way of supplying the phosphorus needs of widely occurring phosphorus-deficient soils in tropical areas. Phosphorus is the most limiting element for crop production in large expanses of Latin American soils. These soils are acid (pH below 5.5), are low in calcium and sometimes magnesium, and have relatively high amounts of reactive iron and aluminum which combine with soluble phosphates to form very insoluble compounds. Acid-tolerant crops and varieties are being identified so that soil acidity *per se* may not be a problem; however, secondary effects of aluminum and manganese toxicity can be important. Such soils are responsive to the direct application of finely ground phosphate rock, and much of IFDC's phosphate program has been concerned with investigating this possibility in cooperation with the International Center for Tropical Agriculture (CIAT).

Direct application of phosphate rock has several advantages:

1. Low cost, especially for indigenous rocks.
2. Low capital investment.
3. Little technical skill required.
4. Small energy requirement.
5. Suitability of rocks that are unsuitable for chemical processing (high carbonate or high chloride rocks for example).
6. Avoidance of long delays for constructing processing equipment.
7. Low importance of economy of scale and capacity utilization.
8. Supply of calcium and sometimes other nutrients in addition to phosphorus.
9. Utilization of nearly the total P value of the mined product. (Beneficiation and processing of some ores to a product satisfactory for conventional processing may incur losses of as much as 50% of the mined product.)

The reactivities of phosphate rocks vary widely; chemical tests commonly used to indicate reactivity are solubility in formic acid, citric acid, and neutral ammonium citrate. I understand that the European Economic Community (EEC) recommends the formic acid method and suggests that phosphate rock for direct application should be at least 50% soluble in this reagent. Of the rocks we have worked

with, those from North Carolina, Sechura (Peru), and Gafsa (Tunisia) are the most reactive; their solubilities in formic acid range from 72% to 85%. We have also worked with rocks of medium and low solubility in the range of 20%-40%. Some of these rocks were from small deposits in developing countries.

Each of the chemical methods showed a fairly good correlation with short-term agronomic response. However, in long-term tests the reactivity of the rocks was not so important. For example, in one series of tests on grassland in Colombia, only the first cutting response was proportional to reactivity; thereafter, the effectiveness of all rocks increased and approached or surpassed that of triple superphosphate (TSP) by the third cutting. Cumulative 4-year yields were essentially equal for all rocks and fully equal to those of TSP.[17]

It is not easy to separate the response to phosphorus in phosphate rock from the response to calcium in these tropical soils that are deficient in both. Liming the soil tends to decrease or delay the effectiveness of phosphate rock, whereas it increases the effectiveness of soluble phosphates. Thus, the phosphate rocks are often more effective than TSP on unlimed soil but may be less effective on limed soil, particularly in the year of application. As a practical matter, the expense of the combination of liming and applying soluble phosphate is likely to be prohibitive in many of these areas.

IFDC has studied the granulation of finely ground phosphate rock, using 3%-5% of a soluble salt as a binder. Such granules disintegrate to a powder in moist soil or during rains in the case of surface applications. Granules of the usual size (6- to 16-mesh) are agronomically effective for surface application on grassland, but when incorporated in the soil they are much less effective for the first crop than the powdery material. IFDC has developed a process for minigranulation of ground phosphate rock using an experimental pinmixer. Minigranules (48- to 100-mesh) are dust free and agronomically as effective as ungranulated ground phosphate rock for mixed or surface application.

Granulation is an extra expense that is not always warranted but may make the product more acceptable in some markets. Application of ground rock may be attractive in areas where suitable equipment is available. TVA has demonstrated that suspensions containing 60% of ground North Carolina rock in water can be made and applied satisfactorily.[23] Satisfactory suspensions of ground rock and potash (0-12-12) and rock, potash, and elemental sulfur (0-10-10-5S) also were prepared.

When using phosphate rocks of medium or low reactivity, it may be desirable to supply some water-soluble P_2O_5 for quick response, in combination with ground rock for long-term effect. IFDC has prepared granular products of ground rock, partially acidulated with sulfuric or phosphoric acid. Short-term response (6 weeks) was directly proportional to P_2O_5 water solubility; long-term response has not been fully evaluated.

An interesting phenomenon is the unusually good performance of fused calcium magnesium phosphate called "thermophosphate" on tropical soils of Latin America. This product is made by fusing phosphate rock with magnesium silicate minerals, usually serpentine or olivine. It is produced in many small plants in China and less extensively in Japan, Korea, and Brazil. It is reported to be quite popular in Brazil, although production is small; demand exceeds the supply even though the price is 10% higher than superphosphate.

Tests at CIAT have confirmed that crop response to thermophosphate is substantially greater than to TSP on a Colombian soil.[24] Further tests show that the effectiveness of thermophosphate was due to a combination of phosphorus, magnesium, calcium, and silicate; it was equalled by a combination of TSP, magnesium oxide, and calcium silicate.

The process for making thermophosphate is simple, and phosphate rocks that are unsuitable for chemical processing may be used. However, the process is energy intensive. There is an abundant hydroelectric potential in parts of Latin America which may help overcome this disadvantage.

The experience with thermophosphate is interesting mainly as an example of a fertilizer that was not successful in temperate-zone agriculture but is unusually effective on some tropical soils. Thermophosphate was first made commercially in the United States (California) in the 1950s. It was not commercially successful mainly because it was less effective than water-soluble phosphate on our Western soils which are generally alkaline or calcareous. Another lesson is that we should not confine our thinking to N, P, and K. Although not uniquely true of tropical agriculture, some of the secondary elements seem more likely to be deficient in tropical than in temperate zones. In Brazil, for example, scientists are finding that the gypsum that is discarded in making high-analysis phosphate contains secondary elements that are badly needed on some Brazilian soils.

Sulfur Fertilizers

Sulfur deficiencies in the tropics and subtropics appear to be much more common than in the temperate zones. This is probably true for two reasons. First, leaching losses are high in the tropics, and sulfur is a very mobile nutrient that is subject to losses through leaching as nitrogen is. With lower organic matter content and lower exchange capacities of the soils, sulfur and other mobile nutrients are more subject to leaching. Second, with less industrialization, less sulfur is returned to the soil from the air.

Unfortunately, most developing countries have adopted the developed countries' major nutrient (N, P, and K) approach. I contend that sulfur should be considered as a major nutrient in large areas of tropical and subtropical agriculture. To establish that sulfur is a major nutrient and should be treated as such in fertilizers for the tropics and subtropics will take much education and may well be a slow process.

The major sulfur-containing fertilizers, ammonium sulfate and single superphosphate, are rapidly disappearing and becoming almost nonexistent in world trade. These products are discriminated against primarily because their value is calculated only on their N and P content with no value recognized for sulfur. On this basis they have a low analysis and cannot compete on a unit of N and P cost comparison.

IFDC is initiating a program to delineate the major areas of sulfur deficiency and to find satisfactory solutions for including sulfur in the fertilizers for these areas.

We do know that sulfur oxidation is highly dependent upon temperatures (Figure 9).[25] With higher soil temperatures in the tropics, there is strong evidence that elemental sulfur is a good sulfur source in the year of application even without fine grinding although it is an unsatisfactory source for cool climates when rapid response is desired.[26]

Potassium Fertilizers

To date, IFDC has not identified any real contribution it can make in improving potassium fertilizers or in assisting the developing countries in utilizing indigenous potash mineral deposits. Since IFDC's approach has been to focus its efforts on new or improved fertilizers,

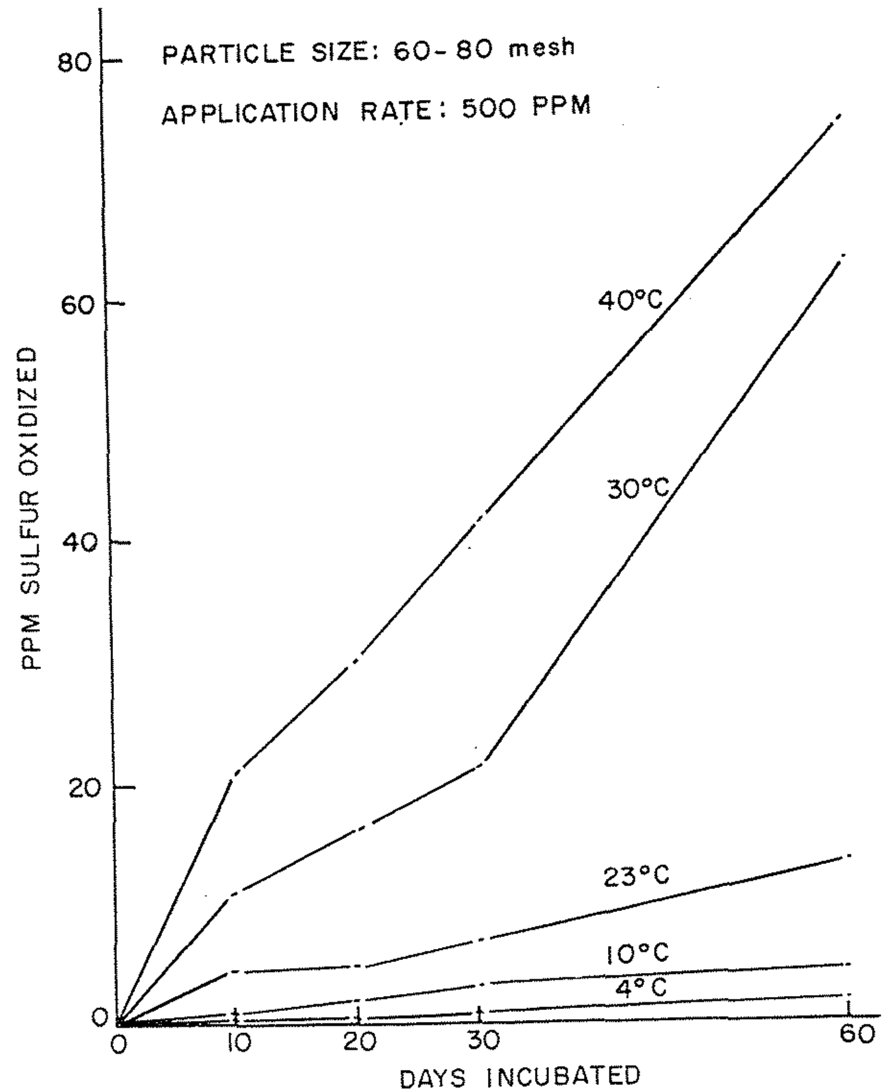


Figure 9. The Relationship Between S Oxidation Rate and Temperature in an Incubation Experiment.

work on potash has received low priority. There is some evidence that there may be a need to reexamine carnallite as a potassium source for those areas of the world where sylvite is not available. Some effort on this may be justified in the future.

As stated previously, in 1981 we, in cooperation with IPI and PPI, assessed the potash situation in the developing countries and determined what IFDC's role should be.

Other Nutrient Fertilizers

Both calcium and magnesium are required in large quantities for efficient crop production. The conventional wisdom in the developed countries is that these nutrients can best be supplied as soil amendments by liming, and at the same time, adjusting the pH of the soil. Probably, the same approach should be followed in the tropics and subtropics wherever it is logistically and economically feasible. There are, however, situations where the liming approach will not be economically feasible, and either or both of these nutrients should be included in the fertilizer. Although IFDC recognizes this problem we are again relying on the study-survey with IPI and PPI to give us our initial guidance.

Closely tied with calcium and magnesium is the acidity of many conventional fertilizers. If some economical way can be found to include these nutrients in the fertilizer, the fear that fertilizers will further aggravate the soil acidity problem can be somewhat alleviated.

Micronutrient fertilizers may eventually become a fertile undertaking for IFDC. There is little doubt in our minds that as crop yield increases, micronutrient fertilization will be much more important in the tropics and subtropics than it is in temperate agriculture. We wish we had the budgets, facilities, and staff to address these problems. Until the extent of the problems and the indigenous mineral deposits can be inventoried, IFDC cannot delineate programs to which it can contribute. Based on the information available to me at present, I believe that zinc should have an early priority.

In summary, the role of fertilizers in feeding the world is great and is becoming widely recognized. Much of the increase in food should come from increased production in the tropics and subtropics where food shortages are the most severe. It is evident that fertilizers for tropical and subtropical agriculture often should be different from those for temperate-zone agriculture. Although IFDC is a young organization, I am proud of what we have accomplished to date. I have great anticipation of what we will accomplish in the years ahead.

References

1. Anderson, R. G. 1975. "The Fight for Survival," 13th Annual General Meeting of the International Superphosphate Manufacturers' Association (ISMA), May 29, 1975, San Francisco, California U.S.A.
2. The World Bank. 1980. *World Development Report, 1980*, Washington, D.C. U.S.A.
3. President's Science Advisory Committee. 1967. "Water and Land," *The World Food Problem*, Vol. II, *Report of the Panel on the World Food Supply*, The White House, Washington, D.C. U.S.A.
4. McNamara, Robert S. 1980. Address to Consultative Group on International Agricultural Research, November 15, 1980, Brussels, Belgium.
5. International Rice Research Institute (IRRI). 1979. "Farm-Level Constraints to High Rice Yields in Asia: 1974-77," Los Banos, Philippines.
6. Takase, K., and T. Wickham. 1976. "Irrigation Management as a Pivot of Agricultural Development in Asia," IN *Asian Agricultural Survey II*, Asian Development Bank, Manila, Philippines.
7. International Fertilizer Development Center (IFDC). 1979. *Fertilizer Manual*, R-1, p. 20, Muscle Shoals, Alabama U.S.A.
8. Munson, Robert. 1980. "Potassium, Calcium, and Magnesium in Tropical Agriculture," unpublished data, International Fertilizer Development Center, Muscle Shoals, Alabama U.S.A.
9. Food and Agriculture Organization of the United Nations (FAO). Several publications of FAO, Rome, Italy.
10. United Nations Industrial Development Organization (UNIDO). 1978. "Second World-Wide Study of the Fertilizer Industry," Vienna, Austria.
11. FAO. 1980. Current Fertilizer Situation and Outlook, Commission on Fertilizers, Sixth Session, Rome, Italy.
12. Stangel, P. J. 1980. "The World Fertilizer Sector—at a Crossroads," International Fertilizer Development Center, Muscle Shoals, Alabama U.S.A.
13. The Fertilizer Institute (TFI). 1980. *1979 Energy Use Survey*, (a report to TFI members), Washington, D.C. U.S.A.

14. Mudahar, M. S., and T. P. Hignett. 1981. "Energy and Fertilizers, Policy Implications and Economic Implications," (report under preparation), International Fertilizer Development Center, Muscle Shoals, Alabama U.S.A.
15. International Center for Tropical Agriculture (CIAT). 1977. *Annual Report*, Cali, Colombia.
16. Hignett, T. P. 1980. "Fertilizer Studies for Developing Countries," Fertilizer Industry Round Table, October 28-30, 1980, Atlanta, Georgia U.S.A.
17. Parish, D. H., L. L. Hammond, and E. T. Craswell. 1980. "Research on Modified Fertilizer Materials for Use in Developing Country Agriculture," Presented at 180th National Meeting of the American Chemical Society, Las Vegas, Nevada U.S.A.
18. Roger, P. A., S. A. Kulasoorija, A. C. Tirol, and E. T. Craswell. 1980. "Deep Placement: A Method of Nitrogen Application Compatible with Algal Nitrogen Fixation in Wetland Rice Soils," *Plant and Soil*, 57(1):137-142.
19. Bixby, D. W. 1978. "The Outlook for Sulfur," *Proc. of the 29th Annual Meeting of the Fert. Ind. Round Table*, 12-17.
20. Stowasser, W. F. 1979. "Phosphate," U.S. Bureau of Mines, Mineral Commodity Profiles, Washington, D.C. U.S.A.
21. "Phosrock's 15% Increase Holding Off Till New Year." 1981. *Fertilizer International*, No. 139, p. 1.
22. "Phosphate Rock Trade by Sea." 1980. *Phosphorus and Potassium*, 109:25-31.
23. Achorn, F. P., and Homer L. Kimbrough. 1978. "New Processes and Products for the Fluid Fertilizer Industry-Phosphates," IN *NFSA Round-Up*, National Fertilizer Solutions Association, Peoria, Illinois U.S.A.
24. Fenster, W. E., and L. A. Leon. 1978. "Utilization of Phosphate Rock in Tropical Soils of Latin America," Proceedings of Seminar on Phosphate Rock for Direct Application, IFDC S-1, Muscle Shoals, Alabama U.S.A.
25. International Fertilizer Development Center. 1979. *Sulfur in the Tropics*, T-12, Muscle Shoals, Alabama U.S.A.
26. Li, P. 1965. "The Oxidation of Elemental Sulfur in Soil," Master of Science Thesis, University of Minnesota, Minneapolis, Minnesota U.S.A.