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# Fertilizers

Many of the problems of tropical agriculture that relate to fertilizer effectiveness are basically the same as, or similar to, those in temperate regions. The differences are mainly in the degree of severity; that is, the problems that affect the effectiveness of fertilizers in the tropics are often more serious and restricting than their counterparts in temperate regions. In many cases, conventional fertilizers should be satisfactory, in others, new fertilizers or modifications of existing ones may be needed to attain high yields.

Higher cost is a very important obstacle to adoption of any fertilizer modification. This is especially critical in countries where cost of conventional fertilizers is high relative to the price received for the crop. However, this factor is not given priority here, since a "forward look" into the future is desired. Several examples in fertilizer development have shown that costs usually decrease as production increases.

The main objectives of this chapter are to discuss possibilities for new fertilizers or fertilizer modifications of special interest for the deeply weathered soils of the humid tropics and to offer possible solutions to soil fertility problems of importance in those areas. Background information on the historical development of fertilizers

and the chemical characterization of phosphate fertilizers is given in an appendix.

## FERTILIZERS FOR SOIL FERTILITY PROBLEMS

### Nutrient Losses via Leaching

One of the most serious problems limiting the effectiveness of fertilizers in the humid tropics is the potential for high losses of nutrients through leaching. Heavy rainfall coupled with high percolation rates and low base exchange capacities of the soils would be expected to produce especially serious losses of nutrients.

The chief characteristics of fertilizers that relate to losses of nutrients are initial solubility and reactivity. All conventional nitrogen and potassium fertilizers are water-soluble; the compounds involved are dissolved almost immediately upon application, and the nutrients are then subject to losses, with the exception of forms that are attached to charged sites of clay or organic matter. Whereas losses of ammonium, nitrogen, or potassium are low in most soils of temperate regions, the deeply weathered tropical soils often possess such low cation exchange capacity that significant losses can occur. To reduce the rate of initial dissolution, several approaches have been tried. One is to use a nitrogen or potassium source that has a low rate of dissolution in water. The rate of dissolution of such compounds decreases as the amount of surface area exposed decreases; hence, large particles have a lower rate of dissolution than finer particles. Examples of nitrogen compounds are oxamide (DeMent *et al*, 1961) and isobutylidene diurea (IBDU) (Hamamoto, 1966). One potassium compound that has some agronomic potential is potassium calcium pyrophosphate (Engelstad, 1968). Of these, only IBDU is being produced in commercial amounts at present.

Another method of lowering the rate of dissolution is to coat soluble nitrogen or potassium compounds with materials that slow or delay the release of the nutrient source. An example is sulfur-coated urea, developed by the Tennessee Valley Authority (TVA) (Rindt *et al.*, 1968). The soluble urea prill is coated with a combination of elemental sulfur, conditioner, microbicide, and wax to reduce the rate of dissolution. The actual rate of dissolution is affected by such factors as soil temperature, placement, coating weight, and imperfections in the coating. Granular potassium chloride has also been

coated in the same process to form a slowly soluble source of potassium.

Other types of coatings that have been tried are plastics or asphalt applied to the prill and the use of perforated plastic bags.

In the process of lowering the release rate by these means, seed or seedling injury and luxury nutrient uptake are minimized. Also, a more uniform supply of nutrient to the crop can be attained; this may, however, require an admixture of uncoated material to provide some initial supply of nutrient.

Another approach to reducing losses of nitrogen is to restrict the process of nitrification—that is, to prevent the biological transformation of ammonium nitrogen to nitrate. In soils where there is substantial cation exchange capacity, this should reduce leaching losses. Several nitrification inhibitors seem fairly effective in small or closed systems. However, in the field it is often difficult to determine any effects in reducing the rate of nitrification. This seems to be a result of high vapor pressure in certain cases. Also, in the tropics, there is some evidence that the relatively high temperatures quickly inactivate these inhibitors (Private communication, National Institute of Agricultural Sciences, Tokyo).

### Ammonia Volatilization via Topdressing to Upland Crops

It is a very common practice in the tropics to add some nitrogen at planting time and the remainder as topdressing during the growing season. Topdressing of materials such as urea can result in substantial losses of ammonia to the atmosphere. Such losses can be especially serious when urea or ammonium-nitrogen fertilizers are applied to calcareous soils during periods of high temperature and when the soil is undergoing drying (Terman, 1965).

One precaution that could be taken where irrigation facilities are available is to add water soon after application. This will move the urea into the soil before hydrolysis or ammonia release.

Another approach is to use a source such as ammonium nitrate for topdressing. This source usually suffers relatively little loss of nitrogen as ammonia when applied in this way. Ammonium nitrate has been used infrequently in developing countries because of its potential explosive hazard and possible use by dissident groups. Use of ammonium sulfate or calcium ammonium nitrate may be feasible alternatives that have little or no explosive hazard. Also, these carry secondary nutrients that may be needed.

An additional approach could be that of adding some coated nitrogen fertilizer at planting to supply nitrogen for later crop needs. This would be incorporated, and losses would thus be minimized. Also, there would be less need for later topdressing.

## Solubility of Phosphorus Fertilizers

A number of variables influence the effectiveness of phosphorus fertilizers in addition to solubility in water or citrate solutions, or both. Therefore, it is difficult to generalize regarding needed levels of solubility for various crop–soil combinations in the tropics. Soluble phosphorus fertilizers undergo rapid reaction with soil components, forming less soluble precipitates. Some tropical soils "fix" large amounts of phosphorus in less soluble forms—an important problem in many areas. Also, in areas where fertilizer phosphorus is rapidly fixed in unavailable form, higher rates may be needed before crop response occurs.

Research in temperate regions indicates that phosphorus fertilizers applied at planting time should have at least 40 to 50 percent of phosphorus in water-soluble form. This assures an adequate concentration of soluble phosphorus for rapid uptake and early growth stimulation in cooler climates and on alkaline soils. However, in the tropics where the soil pH is quite low, phosphorus fertilizers of lower solubility seem to be effective for many crops. For example, the more reactive rock phosphates with at least part of the phosphorus in citrate-soluble form have been effective in Malaysia, Thailand, and Vietnam.

The TVA has characterized in some detail most of the important rock phosphate deposits of the world. Considerable variation exists in terms of chemical characteristics, citrate solubility, and reactivity with soils. Agronomic research is needed to compare the various rock phosphates found or marketed in the tropics in relation to that of a water-soluble standard such as triple superphosphate. Once adequate agronomic data are available, it should be possible to determine which source would be the most feasible investment in light of transportation costs, delivery price, and other economic considerations.

Other possibilities that might be considered for acid soils are partially acidulated rock phosphate, rock-phosphate–sulfur mixtures, and rock-phosphate–urea mixtures. These can be granulated for convenient handling if they are sufficiently reactive.

Among phosphates of intermediate solubility that could be con-

sidered are the polyphosphates (also called metaphosphates) of calcium and potassium, fused magnesium phosphates, basic slag, and nitric phosphates. Naturally, nutrient content should be considered where transportation distance is considerable.

Some new water-soluble sources of phosphorus may be of interest in relation to tropical soils; these are ammonium polyphosphate and urea ammonium polyphosphate. These sources carry about half of their phosphorus content as orthophosphate and the remainder as polyphosphate. In the United States, they are at least equal in effectiveness to ammonium orthophosphates. They should be tested in tropical soils to determine whether any agronomic advantages over conventional sources might be found.

### Efforts to Improve the Effectiveness of Phosphate Fertilizers

Since water-soluble fertilizers react readily with iron and aluminum in acid soils to form less soluble compounds, greater effectiveness from the fertilizer results from reducing its contact with the soil. Thus, banding or spot placement of the fertilizer near the seed provides greater effectiveness per unit of phosphorus. This might be of real importance in those areas where fertilizers are relatively costly.

Another problem is that of approach to application; this might be identified as the question of "crop versus soil fertilization." The banding or spot approach might be called crop fertilization, that is, where relatively low rates are added near the row as a localized placement to restrict contact with the soil. Fertilization of the soil involves much heavier rates of application where the objective is to satisfy the phosphorus-fixing capacity of the soil. The feasibility of this approach would depend on the capital position of the farmer and his particular planning horizon. Agronomic information should be made available to the farmer to help him make such a decision.

Addition of silicate to the tropical soils of Hawaii has been reported to enhance the uptake of fertilizer phosphorus by sugarcane. Apparently, silica can substitute for phosphorus on the reactive sites in the soil, freeing phosphorus for plant uptake. It might be well to test various silica-phosphate combinations in the effort to enhance the effectiveness of phosphate fertilizers. The TVA tested a reaction product of silica and phosphoric acid several years ago and found it to be a satisfactory source of phosphorus.

Research should be conducted in the tropics to ascertain residual effectiveness of various phosphates. It might be that the less soluble

phosphates have a greater residual effect in the soils than the water-soluble phosphates. The citrate-soluble phosphates (water-insoluble) and the rock phosphates might be of interest in this connection.

### Secondary and Micronutrient Deficiencies

In many of the highly weathered soils of the tropics, secondary and micronutrient deficiencies are important limiting factors for crop production. In addition to the problem of diagnosis, suitable methods of applying the needed nutrients to correct the deficiencies are involved.

Where calcium and magnesium deficiencies occur, the soil pH is probably low, and applications of ground limestone or dolomite can correct the acidity and supply calcium and magnesium. Naturally, care must be taken in liming tropical soils that are subject to "liming injury." For the most part, addition of ground limestone or other amendments via fertilizers does not supply enough liming material to correct soil acidity. There have been instances in which fertilizers have supplied sufficient calcium and magnesium to correct deficiencies where low soil pH *per se* was not a problem. In fact, part of the benefit of calcium phosphates may be to add needed calcium in addition to phosphorus.

Sulfur may be supplied by adding at least part of the nitrogen or phosphorus requirements by means of ammonium sulfate or ordinary superphosphate. The latter contains a substantial quantity of calcium sulfate, a satisfactory source of sulfur. These fertilizers are low in nitrogen or phosphorus, however, and exclusive use of either would not be recommended in areas where transportation costs are high. Sulfur-coated urea, ammonium-nitrate–sulfate, urea–ammonium-sulfate mixtures, ammonium-phosphate–sulfate, and rock-phosphate–sulfur mixtures are other possibilities; elemental sulfur can also be applied alone or added to fertilizers lacking sulfur.

The micronutrients are a special case. Usually, the amounts required for correcting deficiencies are so low that it is difficult to apply sources evenly. However, micronutrient sources can be incorporated with certain macronutrient carriers. The result is that only a single application of fertilizer is required and the micronutrients are added much more uniformly than if added alone. More details regarding incorporation of micronutrients in macronutrient fertilizers are in the literature (Mortvedt and Giordano, 1967; Young, 1969).

Availability to the plant of the micronutrients when added with macronutrient fertilizer is related not only to their distribution but also to a combination of reactions between the respective sources and between the fertilizers and the soil.

Zinc should receive special mention here. Deficiencies in this nutrient are becoming more common each year in both the developed and developing areas of the world. Both flooded and upland crops are showing response to additions of zinc. More attention must be paid to supplying this nutrient if high crop yields are to be attained.

## OTHER SOIL FERTILITY PROBLEMS

### Low pH of Subsoils

In many deeply weathered tropical and subtropical areas, low pH in the subsoils is seriously limiting crop yields. The effects of low pH may be expressed as toxic aluminum or manganese or both and possibly as calcium deficiency. The addition of most nitrogen fertilizers aggravates the acidity problem. Since the use of nitrogen fertilizers is increasing generally in the tropics, the associated problem of subsoil acidity can be expected to become more serious over time.

### Multiple Nutrient Deficiencies and Imbalances

In many of the developing countries of the tropics, nitrogen fertilizers are being applied almost exclusively, even where multiple nutrient deficiencies occur. This is a result of (1) more immediate, visual response to nitrogen in many cases, (2) the construction of nitrogen-production facilities in-country, (3) importation of phosphorus and potassium fertilizers based on scarce foreign exchange.

Improvement of this situation depends on several factors:

- Indigenous sources of phosphorus and potassium should be found and developed.
- Importation procedures of fertilizers should be improved, to increase efficiency of handling and reduce costs.
- Soil testing services and an up-to-date research program should be developed.
- A well-trained agricultural extension service should be established.

### Fertilizer-Variety Interactions

Development of new crop varieties has changed markedly the nature of the yield response to fertilizer nutrients. The yield response curve is now positive in slope over a much wider range in fertilizer application than was true for the older native varieties. Much of this increase in yield can be attributed to greater lodging resistance; thus, heavier rates of fertilizer nitrogen can be applied without causing serious lodging problems.

The development of new varieties and new management systems renders much of the older crop-response data obsolete except in a qualitative way. New experimental programs are needed to obtain data relevant to the changed situation. While farmers' fields will no doubt be used in most cases, modern experimental techniques should be employed for all operations. Improved statistical designs should also be used; these should involve complete replication on each site and at least two nonzero rates of application in addition to a proper control for each nutrient.

Such studies can also be used for economic analysis, thereby extending the usefulness of the data. Where fertilizer cost is high relative to the price of food crops, the economics of fertilizer use will continue to be a very important consideration.

### Tests of New Fertilizers

A number of new fertilizers are being developed. It is customary to test these new materials under local conditions to ascertain their effectiveness compared with that of a standard or known nutrient source. To do this properly, several conditions are required:

- A yield response to the nutrient in question should be obtained.
- In addition to a proper control plot, at least two nonzero rates of the nutrient in question should be employed.
- Modern statistical design should be used; this involves at least complete replication on each site—incomplete or partial replication is not satisfactory.
- Good management should be employed in all phases of the experiment. Yields or responses limited by extraneous factors will be of little value. Adequate levels of other nutrients should be assured.
- Provision for measuring residual effects should be made where

nutrient sources are of low solubility or where losses during the off-season are minimal.

- Statistical analysis of the data should be employed; where relevant, economic analysis of data should also be conducted. The most economic source of a particular nutrient for a given area or country might be determined, based on agronomic performance and delivered prices.

Further details on fertilizer evaluation have been published by Terman and Engelstad (1971).

### Transportation Costs

In many areas of the tropics, the farm-to-market road system will be inadequate for some time to come. In fact, fertilizer and other inputs must yet be carried in by head load in many areas. Then, too, the cost of transporting fertilizer to the final distribution point is often prohibitive on a per-unit-of-nutrient basis. The nutrient content should be increased toward the theoretical limit as a means of offsetting these difficulties.

The TVA has developed laboratory-scale amounts of some experimental fertilizers of very high nutrient content. Typical grades are 55-92-0 and 11-58-39. Some of these could serve as shipping intermediates, but may require some processing at the market area. Others can also be used in direct application, as their performance is equal to that of conventional materials on a per-unit-of-nutrient basis. While these are still only in very early stages of research and development, the potential for tropical regions is marked.

## APPENDIX

### Fertilizer Development in the Temperate Regions

#### *Solid Fertilizers*

The nutrient content of fertilizers used in all countries was low until relatively recent years. In the United States, for example, a significant increase in nutrient content occurred only after 1930. As a re-

sult of the joint efforts of the TVA and the fertilizer industry in the United States, the average nutrient content ($N + P_2O_5 + K_2O$) of U.S. fertilizers rose from 18 percent in 1930 to over 40 percent in 1968.

Another recent change in fertilizers is improved storage and handling properties. One of the initial obstacles to the use of high-analysis solid fertilizers was the tendency to "set-up" or "cake" during storage. However, with the development of granulation and the use of conditioning agents and moisture-proof bags, these problems were overcome and products are now "free-flowing" in field-application equipment. This aids in a more uniform application in the field and a marked reduction in "dustiness"—a disagreeable problem associated with powdered or semigranular fertilizers. Also, farmers who apply fertilizers by hand prefer granular materials.

Granulation is a fairly recent development in the United States, beginning in the early 1950's (Slack, 1966). Since that time, the shift to production of granular fertilizers has been dramatic, largely as a result of new technology and consumer preference. Single-nutrient and multinutrient materials used for bulk blending or direct application are now almost exclusively granular.

Various clays or other absorbent earths are used as conditioners to improve fertilizer handling and storage properties. These conditioners are coated on granule surfaces and serve as anticaking agents. This prevents the formation of intergranular crystals that seem to be responsible for much of the caking problem (Slack, 1966).

Historically, solid fertilizers have been transported in bags. Recently, however, handling and transport in bulk form have become important. One aspect of handling solid fertilizers in bulk form is the blending or mixing of granular materials at local distribution points or at seaports. This approach to formulating mixed fertilizer is called bulk blending and usually results in both high-analysis mixtures and flexibility to meet consumer demands. The fertilizer can then be applied in bulk form or bagged for further handling.

Distribution in bags has been facilitated by significant improvements in bag construction since about 1945. Moisture barriers of the asphalt type have been improved, and barriers in the form of plastic films or coatings have been introduced. At present, there is a trend toward the use of all-plastic bags that offer almost complete resistance, even to rain, and are competitive in price with multiwall paper bags.

*Fluid Fertilizers*

Use of fluid mixed fertilizers in solution (commonly called liquid) or suspension form involve variations of the bulk-handling concept. Advantages of these fertilizers are primarily the greater convenience of handling and application as compared with solids, rather than a price advantage. Such problems as caking, dustiness, hygroscopicity, and segregation—common for solid mixed fertilizers—are avoided with fluids. Significant savings in labor costs may be realized.

The nutrient content of fertilizer solutions has generally been low, since most components have limited solubility in water. However, use of highly concentrated superphosphoric acid has permitted substantial increases in the analysis of the resultant solutions. Because of sequestration properties of the pyrophosphates in superphosphoric acid, its addition to relatively low-cost wet-process phosphoric acid prevents precipitation of impurities that would otherwise occur when this acid is ammoniated.

In suspension fertilizers, at least part of the ingredients are not in solution but are suspended with the aid of a small amount of clay. Suspension fertilizers are higher in analysis than are the corresponding solutions. Various micronutrients and pesticides may be incorporated into and applied with suspensions, provided that the ingredients are physically and biologically compatible. Most suspensions, however, should not be stored for long periods because of crystal growth and settling out of the solids.

## Development of Fertilizer Use in Tropical Regions

Historically, the total fertilizer tonnage used in the developing countries of the tropics has been very low by temperate region standards. Most of this was imported and used on the so-called estate or tree crops. In view of the recent concern for population growth and food supplies, many developing countries are building fertilizer plants within their borders. Several of these countries are approaching self-sufficiency in nitrogen. While much of the phosphorus and potassium material will be imported for some time to come, it is reasonable to expect that most of the fertilizer requirements of the tropics will eventually be produced there. Urea is rapidly replacing ammonium sulfate as a source of nitrogen in much of the developing world. This shift in sources represents an increase in nitrogen content from 21 to 45 percent. The interest in production of urea in develop-

ing countries stems from its high analysis, low raw material cost, and transportation savings, as compared with other nitrogen sources.

Similar trends are taking place in phosphorus sources. Developing countries have begun importing large amounts of ammonium phosphates; however, as they develop their domestic nitrogen supplies, concentrated superphosphate may become the leading imported source of phosphorus. These sources represent substantial increases in phosphorus content, as indicated in the following tabulation:

| Sources of Phosphorus | $P_2O_5$ Content (%) |
|---|---|
| Ordinary superphosphate | 18–20 |
| Concentrated or triple superphosphate | 45–48 |
| Ammonium phosphates | 46–48 |

In addition to an increase in phosphorus content, the ammonium phosphates carry substantial amounts of nitrogen—11 and 18 percent for the monoammonium and diammonium phosphates, respectively. These figures indicate the increases in nutrient content now being realized in many developing regions.

Naturally, these increases in nutrient content represent substantial savings in transportation and handling costs per unit of nutrient, especially important for countries importing most if not all of their requirements In addition to savings in overseas shipping charges, however, the savings in internal distribution costs must be recognized, especially where highways, rail systems, and storage facilities are inadequate.

Thus, it appears that most of the plant nutrients required in tropical countries in the next decade will be supplied by urea, ammonium phosphate, triple superphosphate, potassium chloride, and various combinations of these.

The grades and ratios of mixed fertilizers should be limited to those that can be justified on agronomic grounds. Low-analysis grades generally should be discouraged. It is easier to control the grades and ratios in the early stages of development of a fertilizer industry and use than after proliferation has taken place. Once grades become established, there is considerable resistance to dropping them. The primary consideration should be to keep the nutrient cost low for the farmer, rather than to provide him with a wide choice of ratios and grades.

The ratios must be decided according to soil and crop needs on a

regional basis. Some allowance should be made for shifts in fertility over time; grades should, therefore, be re-evaluated every few years.

Bulk blending of granular materials has real potential in tropical countries. Blends can be bagged or handled in bulk for transport and application. Any desired fertilizer ratio can be easily prepared near the final distribution point.

From an agronomic standpoint, it matters little whether the needed nutrients are applied separately or as a homogeneous mixture. One exception would be the well-known increase in phosphorus uptake that results from placement of nitrogen with banded phosphorus fertilizer. This is a phenomenon that is important only where phosphorus is banded and where phosphorus fertilizer rates are low. For farmers who are not knowledgeable about plant nutrients, the use of a complete fertilizer (i.e., containing all locally needed nutrients) is more practical than the separate purchase and application of two or more materials. For farmers who are knowledgeable about plant nutrients, separate materials may be a feasible choice, offering possible economic advantages and flexibility in application.

## Chemical Characterization of Phosphate Fertilizers

Common nitrogen and potassium fertilizers are water soluble and therefore, pose no problems in initial characterization. Phosphate fertilizers, however, cover the range from zero to high levels of citrate or water solubility; hence, it might be well to describe here the chemical characteristics of phosphate fertilizers. These mainly involve their solubility in various solvents, an indication of the rate of dissolution when applied to soils.

Both water-soluble phosphorus and available phosphorus are used in describing phosphorus fertilizers. In the United States, these two terms are defined by standardized methods of analysis developed and published by the Association of Official Analytical Chemists (AOAC). These standard analytical methods are essential for the successful enforcement of fertilizer control laws.

In the United States, available phosphorus (expressed as $P_2O_5$) is defined as water-soluble phosphorus plus that fraction which dissolves in neutral ammonium citrate solution. Available phosphorus can also be determined directly by ammonium citrate extraction of the fertilizer sample without determining the content of water-soluble

phosphorus. Fertilizers in the United States are guaranteed according to available phosphorus content as determined by solubility in neutral ammonium citrate solution, but not by their water-soluble fraction.

The methods adopted by the AOAC in the United States for control purposes are also employed in certain other countries. Others determine phosphorus content by dissolution in water (particularly for superphosphates). Determinations in Japan and most European countries are based on dissolution in alkaline ammonium citrate solution. There is evidence that the last method provides a better guide to the agronomic effectiveness of phosphorus in ammoniated superphosphates than does the neutral ammonium citrate method.

Common phosphate fertilizers may be grouped into the following categories of solubility according to AOAC procedures:

1. Water-soluble phosphates—ammonium orthophosphates, ammonium polyphosphates, ammonium phosphate nitrates and sulfates, superphosphates, sodium and potassium phosphates, and phosphoric acids.
2. Citrate-soluble phosphates (water-insoluble)—dicalcium and tricalcium phosphates, basic slag, fused serpentine phosphates, and nonorthophosphates (such as calcium polyphosphate) that hydrolyze to water-soluble forms.
3. Mixtures of 1 and 2—nitric phosphates, ammoniated superphosphates. The water-soluble phosphorus content of nitric phosphate fertilizers varies from 0 to 60 percent of the total, depending on the process and formulation used. Most of the water-insoluble phosphorus is citrate-soluble.
4. Citrate-insoluble phosphates—the bulk of phosphorus in phosphate rocks, "colloidal" phosphates, and some precipitated apatites.

The lines of distinction among these classes are not absolute; sample size, sample-to-extractant ratio, and time allowed for dissolution affect the degree of dissolution.

The degree to which phosphates dissolve in water and citrate solutions indicates to a considerable extent how they react in the soil and how effective they are as sources of phosphorus for plants. However, chemical tests are largely empirical and are not of equal value for all phosphates. Also, they do not reflect soil, crop, and climatic conditions that may affect the use of phosphorus by plants.

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