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RESEARCH ON MODIFIED FERTILIZER MATERIALS FOR USE IN DEVELOPING-COUNTRY AGRICULTURE[1]

by

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SUMMARY

Many developing market economy (DME) countries are still far from achieving their stated goal of national food self-sufficiency. All-round improvements in agricultural production are occurring, with an increase in fertilizer use being a key contributing factor. The importance of fertilizer is shown by the fact that the DME countries used more than 18 million nutrient tons of fertilizer N, P_2O_5, and K_2O in 1978/79 and that the growth rate in consumption is more than 7%/year. Any improvement in the efficiency with which nitrogenous and phosphatic fertilizers improve crop yields would have a tremendous economic impact on developing countries by reducing the energy and the capital costs incurred in their production and distribution. Urea is the major source of nitrogen in these countries, particularly those producing rice. Experiments show that the efficiency of nitrogen utilization of broadcast urea by the rice crop is as low as 25%-30%. Point placement of nitrogen in the form of urea supergranules effectively doubles efficiency to 75%-85%. Point placement also permits nitrogen fixation by blue-green algae to continue unimpeded, whereas broadcast urea inhibits fixation. An alternative to point placement is the use of slow-release materials such as sulfur-coated urea (SCU) which has given an efficiency of 46%-78% under field conditions. Research is underway to delineate those areas where SCU and urea supergranules are economically attractive.

In the acid Oxisols, Ultisols, and Andepts, which are major soils of the tropics, phosphorus requirements are generally high. Due to high concentrations of iron and aluminum oxides in these soils, the phosphorus retention capacity in the Oxisols and Ultisols is typically in the range of 500-1,000 ppm of the added P while Andepts can fix more than 1,000 ppm P. Some finely ground phosphate rocks and partially acidulated phosphate rocks have been found to be effective P carriers under these conditions. Depending on soil properties, crop type, and management, finely ground rock with high, medium, and low citrate solubilities ranges from 80%-100%, 60%-80%, and 30%-60% in effectiveness, respectively, when compared with the initial crop responses to triple superphosphate (TSP). However, high residual effectiveness from phosphate rocks due to continuous dissolution has resulted in crop production equal to or better than TSP in long-term trials. The poor level of initial efficiency of low solubility rock can be improved by acidulation using only 20% of the H_3PO_4 required for TSP production to give materials agronomically comparable with TSP. These alternative sources of phosphate are of great interest to many areas where

expensive imported phosphates could be replaced by low technology materials made from local deposits.

INTRODUCTION

The term "developing country" is used to describe those countries of the tropics and subtropics characterized by generally low per-capita incomes and where the value of agricultural production is a major component of the gross domestic product. The term "developing market economy" (DME) country is applied to the non-Communist developing countries.

Many of these countries, despite the fact that most of their active population is engaged in agricultural production, suffer increasingly from either chronic or periodic food shortages which can only be met by increasingly heavy imports from abroad. These countries have therefore generally made food self-sufficiency a stated goal of national policy.

Food production can be increased by expanding the cultivated area or by increasing yields per unit of area or by a combination of both of these approaches. However, because food shortages have developed in most countries over a long period of time due to population growth, existing fertile land resources have usually already been heavily exploited, meaning that low soil fertility limits both current production and future expansion of the cultivated areas. Economic neglect of the small food-producing farmer has compounded the problem of low food production in many developing countries.

Table 1 shows the recent changes occurring in fertilizer consumption and highlights the growing importance of the developing countries as fertilizer consumers. Nitrogen (N), with a consumption of over 10 million tons, is the key fertilizer input for the DME countries, followed by phosphate (P_2O_5) at 5.6 million, and potash (K_2O) at 2.9 million tons. Although levels of use and particularly the growth rate performance give reason for a cautious optimism, the consumption of plant nutrients per hectare of arable land is still very low for most DME countries (Table 2).

The increase in crop yields due to fertilizer use obviously varies widely with both crop site and season; however, the average figure, which is widely accepted, is that 1 kg of fertilizer nutrient ($N + P_2O_5 + K_2O$) will give 10 kg of additional wheat or rice. This tenfold-weight relationship between fertilizer and the additional food it can provide is the reason fertilizer is regarded as a key strategic material in most developing countries.

Given the foregoing, it would be expected that fertilizer use would have become more or less universal. However, poor crop varieties, lack of farmer knowledge, inefficient input delivery systems, inadequate working capital, and finally the low capacity of the existing crop marketing systems to handle any increase in farm output while maintaining a reasonable rate of return to the farmer are all serious constraints to fertilizer use over large areas in many developing countries. Where fertilizer is used, it is essential to exploit to the full any opportunity which could lead to the improved efficiency of its use in terms of crop-production economics, and it is in this context that the research and development programs of IFDC have been established.

IFDC RESEARCH ON FERTILIZERS FOR DEVELOPING COUNTRIES

IFDC has multifaceted and multidisciplinary research and development programs covering the whole range of activities associated with the fertilizer sector, namely industrial technology, economics, agronomy, marketing, and training programs.

Although work is underway with several plant nutrients and their fertilizer carriers, the major effort to date has gone into comprehensive nitrogen and phosphorus programs because these two nutrients are key constraints to the improved grain production performance of most developing countries. Any improvement in the efficiency with which nitrogenous and phosphatic fertilizers improve crop yields would have a tremendous economic impact on the developing countries by reducing the energy and capital costs incurred in their production and distribution.

Two approaches to the problems of improving the economics of fertilizer use in the developing countries are illustrated by specific parts of IFDC's nitrogen and phosphorus programs. As part of the overall nitrogen program one research group is studying in depth the fate of nitrogenous fertilizer when applied to flooded rice and studying materials and practices which could lead to a reduction of the very large fertilizer nitrogen losses which can occur when a rice crop is fertilized. This work is important because most of the nitrogenous fertilizer used in the developing world for food-crop production is used on the rice crop in the form of prilled urea, and considerable scope for improving the efficiency of this material as a rice fertilizer exists.

Specific parts of the phosphorus program in contrast have concentrated on the very diverse problems of using national phosphate rock deposits to replace or supplement imported phosphatic fertilizers. The direct application of ground local rock is the simplest technology being examined; however, the production of phosphatic fertilizers using both conventional and innovative technologies is also being

studied. The final choice of fertilizer material to be produced in any one country will depend on a full economic assessment of the production, distribution, and use alternatives.

This paper describes some of the laboratory, greenhouse, and field results from IFDC's research; for the technological aspects of the various fertilizer materials use in this work, the reader is referred to the relevant IFDC and Tennessee Valley Authority (TVA) literature.

Research on Rice Fertilization With Urea

Asian rice farmers have for centuries practiced a system of rice production that, while maintaining a degree of soil fertility, ensured modest but stable yields without the use of chemical fertilizers. Population pressure, however, has forced governments and farmers to seek ways to increase rice yields. High-yielding, semidwarf varieties of rice have provided the genetic potential for increased rice yields, but this potential cannot be achieved without the application of nitrogen fertilizers.

Unfortunately, the efficiency with which fertilizer nitrogen is used by the rice crop can be very low. Mitsui (1954) cites figures of 30%-40% for the utilization of fertilizer nitrogen by rice, and later work has generally confirmed this poor level of performance.

Fried (1976) and his coworkers using ^{15}N-labeled ammonium sulfate on a rice crop confirmed some 14 years ago that nitrogen uptake could be increased by 30%-50% by deep placement of N fertilizer. The possibilities for the improvement of nitrogen efficiency in rice production have been reviewed by Parish (1979), and this author concluded that specific placement of urea (the major nitrogenous fertilizer of Asia) in an economical way still remained the major problem for the small rice grower. Mechanical placement of prilled urea or of urea solutions, hand placement of large urea particles (supergranules or briquettes), and industrial production of various coated urea particles (TVA's sulfur-coated urea [SCU] and variations of this such as sulfur-coated forestry-grade urea have been the most intensely tested materials) all offer promise. The method chosen in the end will depend on the general availability of the new technology and its relevance to the small-farm situation.

IFDC has developed a basic research program to quantify the mechanisms of fertilizer nitrogen losses and to identify possible ways of reducing these losses. Much of this research has been conducted in cooperation with the International Rice Research Institute (IRRI) in the Philippines. Additionally, IFDC, in association with IRRI, has sponsored the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) in which researchers from 16 rice-growing countries are cooperating in comparing various fertilizer treatments and materials.

IFDC has also established field-testing programs in cooperation with various national organizations; the aim here is to develop a volume of reliable field data on the field behavior and farmer acceptance of modified urea materials sufficient to influence national policy planning. Results from India and the Philippines are used to illustrate this activity.

Mechanisms of Nitrogen Loss

The low efficiencies of nitrogenous fertilizers when applied to rice have generally been ascribed to leaching losses, volatilization losses of ammonia following enzymatic hydrolysis of the urea to ammonium carbonate, and also gaseous losses of N due to the denitrification reaction. The assessment of the actual degree of nitrogen loss by various routes is currently being intensively studied by IFDC, both in the United States and at the IRRI facilities in the Philippines, and some interesting results are being obtained.

Measurements of the concentration of urea and ammonium in the floodwater of different fertilizer treatments (Figure 1) show that broadcast urea produces high concentrations; whereas, deep placement or the use of SCU reduced concentrations considerably. The rapid decline in ammonium concentrations is associated with the high temperatures and high pH of the floodwater, indicating that nitrogen losses due to ammonia volatilization are potentially a major cause of the inefficiency of broadcast urea. High pH values at midday are caused by depletion of dissolved CO_2 by algae growing in the floodwater. As algal growth is stimulated by high concentrations of urea and ammonium, the amplitude of the diurnal pH fluctuation is greatest in the broadcast urea treatments.

Roger, Kulasooriya, Tirol, and Craswell (1980) have shown that this stimulation of algal growth when urea is broadcast on a paddy is due primarily to the increased growth of the green algae which compete with the rice plant for the fertilizer nitrogen.

In contrast, the growth of the desirable blue-green algae, which fix nitrogen, is suppressed by the presence of urea or ammonia in the floodwater following N fertilization. The use of deep-placed urea (as supergranules) and of SCU, which both give lower levels of urea and ammonia in the floodwater, distorts the pattern of algal growth much less than does broadcast urea. This fact is a point of great importance when considering the development of integrated systems of nitrogen management which could maximize both nitrogen fixation and fertilizer efficiency.

In addition to ammonia loss, another major cause of nitrogen loss from paddy soils is thought to be nitrification-denitrification. Nitrogen is oxidized to nitrate in the oxidized surface layer of soil and denitrified in the underlying anaerobic layer. One of the authors (Craswell) has measured the evolution of nitrous oxide (N_2O). The fluxes were quite small (<100 ng N_2O-N/m^2/second) but

did indicate that denitrification was occurring, particularly from broadcast urea. Since N_2O is only a minor product of the process, no firm conclusion can be made about the relative roles of nitrification-denitrification versus ammonia volatilization in determining nitrogen fertilizer efficiency. However, the results show that any fertilizer practice which reduces the concentration of nitrogen in the floodwater is likely to reduce losses by both mechanisms.

Because urea is not adsorbed by the soil, it can move throughout the soil profile with the drainage water. Field trials with urea supergranules show that these materials can perform poorly on coarse-textured soils, and leaching losses of urea are probably the cause. An intensive program to quantify the effects of various soil parameters on the performance of urea, SCU, and urea supergranules is underway with the objective of delineating areas specifically suitable for each material.

Field Trials Comparing Urea, SCU, and Urea Supergranules

In order to increase the very low efficiency of nitrogenous fertilizers for rice production, two methodologies have been generally recommended to the rice farmer. These are: (1) the placement of the nitrogenous fertilizer (in the amide or ammoniacal form) in the reducing zone of the soil and (2) the use of split applications of fertilizer at specific plant development stages.

The placement recommendations, while based on sound scientific fact, are not practicable; a broadcast dressing of fertilizer incorporated into the soil by a harrowing or a weeding operation is the nearest approach to deep placement which can be achieved by most farmers.

For split applications, the basic concept is the provision of adequate nitrogen to the crop during peak demand periods while avoiding the situation whereby large dressings of urea are subject to loss through direct leaching, through ammonia volatilization, or by nitrification with subsequent loss of nitrogen by leaching or denitrification.

The efficiency of a nitrogenous fertilizer is expressed in several ways. The scientist uses the apparent nitrogen recovery or utilization which is a measure of fertilizer nitrogen uptake by the total aerial portion of the crop. At the farm level, however, the agronomic and economic efficiency of the fertilizer is of greater interest. Agronomic efficiency is defined in terms of crop yield increase per unit of nutrient applied at a chosen rate. Economic efficiency is the agronomic efficiency expressed in terms of crop value and fertilizer cost.

In field trials when comparing the efficiency of urea (as prills) with that of modified urea materials such as SCU and urea supergranules, it is usual to use the recommended split treatment

of urea as the standard for comparison. Recent research by Craswell and De Datta (1979) has shown that the farmers' practice and the recommended split both give apparent nitrogen recoveries of only about one-third; comparative data from the same experiments give apparent recoveries of nitrogen from SCU and urea supergranules (USGs) of 78% and 85%, respectively. These data show the wastefulness of present practices and underline the need for a completely new approach to the fertilization of rice with urea.

IFDC has provided modified urea materials for testing in both international and national groups, and results from the major field programs are given below.

Results From the INSFFER Network--Details of the experiments carried out to date under the INSFFER network are given in Table 3 and show that eleven countries are actively engaged in the evaluation of modified urea fertilization technologies.

Table 4 gives a summary of the INSFFER results to date in terms of the agronomic efficiency of the methodologies and materials used to apply the urea.

The application of a 50% urea solution in water by a modified plow did not give satisfactory results because most of the solution entered the supernatant floodwater and, therefore, behaved no differently from a dressing of prilled urea broadcast directly into the floodwater. Because urea is very hygroscopic the use of urea solutions in the humid tropics appears attractive, and work on small liquid applicators is receiving further attention. The USGs performed well; they increased the agronomic efficiency of urea by more than 30% over the best split practice. The point placement of solid urea as typified by the placement of USGs is labor intensive, and unless a mechanical applicator is available use will be restricted to those areas with high unemployment; such areas occur in India, Bangladesh, and Indonesia.

The SCU (TVA's regular granular material with a release rate of 20% in 7 days) also performed well under a wide range of conditions. The attraction of SCU is that it can be used in a single broadcast treatment; thus, its use is particularly relevant to the type of poor management so typical of an Asian rice farm.

Results From Hindustan Fertilizer Corporation (HFC) India--Since 1977 IFDC has been working with HFC on comparisons between the point placement of urea (as represented by urea supergranules or briquettes) and broadcast coated materials (TVA sulfur-coated granular urea, 20% release in 7 days) when used in small farmer fields.

Table 5 summarizes the comparisons made in terms of the reliability of the new technology for the small farmer. In almost half of the trials the modified ureas did not give a significant

increase in yield over the split prilled urea treatment. Farmers in developing countries have a strong aversion to risk, and unless a new technology carries a low risk, they will not accept it. Table 6 contains preliminary analyses from selected trials which show that the modified urea materials do have both the agronomic and economic potential to correct the current wasteful use of urea.

Using the response data and estimated application costs for USGs and production costs for SCU, the optimum rates of N for each material and the agronomic and economic efficiency have been calculated.

Yields and net profits per hectare are higher with USG and SCU than with prilled urea, and this is strongly reflected in the agronomic efficiency which has increased by about 50% with both of the modified urea materials. Results of the Indian work show that refinement of the field trials is needed in order to identify factors affecting the consistency of performance of the new materials

Results From the Philippines National Food and Agriculture Council (NFAC) Fertilizer Program--NFAC, with the assistance of FAO, has been running a series of fertilizer trials in small farmers' fields since 1972 with the objective of developing sound fertilizer recommendations and creating farmer interest in the use of correct fertilization and agronomic practices.

IFDC was interested in obtaining field results and farmer reaction to materials having a particle size larger than the conventional prilled material for two reasons:

1. An increase in particle size by granulation gives better physical properties to the urea in terms of density and hardness.

2. The granular material is an ideal substrate for coating, and as surface area per unit of weight decreases rapidly with increasing particle size, a reduction of coating costs by increasing granule size is possible.

Details of commercial urea products are as follows:

	U. S. Standard Mesh Size	Assumed Weight, g/particle	Approximate Surface Area, cm^2/g
Prilled urea	-8+20	0.0035	26.2
Granular urea	-6+14	0.01	18.3
Forestry-grade urea	-3+5	0.1	8.6

Sulfur-coated forestry-grade urea with 20% water solubility after 7 days was prepared and tested in the NFAC fertilizer program.

A summary of the agro-economic results from the first series of trials is given in Tables 7 and 8, and yield response curves are shown in Figures 2 and 3.

The wet-season and dry-season trials have been separated since solar radiation is much lower in the wet season due to cloudiness, and this results in generally lower yields and a reduction in crop response to nitrogen.

The graphs have been marked to enable comparisons between urea and SCU at typical farmer rates of N application, 60 kg N and 70 kg N/ha, in the wet and dry seasons, respectively (Figures 2 and 3).

Unlike the results from India all of the NFAC results showed a positive effect from the use of SCU. This may have been due partly to the fact that following standard farmer practice the initial split dressing of urea was not incorporated by harrowing.

These experimental results are important because they demonstrate clearly that the current methodology of applying urea to the rice crop is inefficient and that modifications of the urea have great potential as efficient nitrogen fertilizers for the small rice farmer.

The trials just described showed that farmers had no difficulty in spreading the larger forestry-grade size material in the fields. Some uncoated forestry-grade urea was therefore distributed. Results indicate that this material should be more fully tested since most farmers involved were convinced that not only was it easier to apply than prilled urea but that agronomic performance was also better. In addition to the uniformity of spread, mud and canopy penetration of the applied urea could be expected to affect the agronomic performance of the urea, and the apparently better performance of the denser and heavier forestry-grade material was ascribed to an improvement in these factors.

This effect of particle size on the agronomic value of both uncoated and coated urea needs much more intensive study.

Research on Phosphate Materials

While it is recognized that the same types of chemical, physical, and biological processes may be operating in the soil in both temperate and tropical regions, the rate and extent of system activity can and do result in considerable contrasts. For example, in South America it has been estimated that there is over 1 billion ha of acid, infertile Oxisols, Ultisols, and Inceptisols (Table 9). This represents 72.6% of the total land area while soils with the same classification in the United States comprise only 13.8% of the total land area. In South America these soils are generally

acid, are low in both total and available P,[1] and have a tendency to adsorb large quantities of applied fertilizer P. Sanchez (1976) indicates that the P-retention capacity in the Oxisols and Ultisols is typically in the range of 500-1,000 ppm of the added P while Andepts (Inceptisols) can fix more than 1,000 ppm P.

Due to this requirement for phosphorus and especially following the sharp increase in phosphate rock prices during 1974/75, there have been intensified exploration efforts which have identified new phosphate resources for exploitation. The most significant of these developments has occurred in Brazil where about 1 x 10^6 tpy is now being produced from igneous deposits at Jacupiranga, Araxa, Tapira, and Catalao (McClellan, 1979). In all, there are some 20 deposits located in tropical Latin America (Figure 4).

IFDC has developed a research program on phosphates which is strongly oriented toward assisting developing countries to utilize their indigeneous resources. Much of the agronomic research on phosphates in South America has been conducted in cooperation with CIAT in Cali, Colombia. The aim is to select, adapt, or develop technology that is the most cost effective in meeting the needs of agriculture with the resources (raw materials, energy, infrastructure, etc.) at hand. This approach involves developing or identifying phosphate fertilizers that are well suited to tropical and subtropical soils and, thus, involves agronomic, technical, and economic aspects. Application or adaption of conventional technology may or may not be the best choice.

Direct application of finely divided phosphate rock may be one of the cheapest ways to supply P to crops in large areas of the acid soils in the tropics and subtropics. The degree to which direct application will be effective is determined by a number of interrelated factors. These include but are not limited to (1) the reactivity, or potential, of the rock source as determined by the chemical composition of the apatite; (2) the physical propertie of the rock; (3) the properties of the soil (acidity, available P, exchangeable Ca in the soil, and P sorption capacity; (4) the type of crop and cropping system; (5) the method of application; and (6) the time of reaction.

Chemical Reactivity of Phosphate Rocks

The Oxisols, Ultisols, and Andepts described above are soils, which possess properties conducive to the dissolution of directly applied ground phosphate rock. They are acid, possess high P-sorption capacity, and generally exhibit only low concentrations of P in the soil solution and exchangeable Ca in the soil. Still, the

1. A survey conducted at the International Center for Tropical Agriculture (CIAT) in Cali, Colombia, indicates that at least 75% of these are potentially productive soils with varying degrees of P deficiency.

effectiveness of each potential rock source for direct application will be determined by the chemical reactivity of the phosphate rock. It has been shown that the reactivity depends on the degree of carbonate substitution for phosphate in the apatite structure (Lehr and McClellan, 1972) and that several solubility tests are suitable for estimating reactivity (Chien and Hammond, 1978). These include extraction with neutral ammonium citrate, 2% citric acid, 2% formic acid, and acid ammonium citrate, pH 3. Based on these measurements, it has been possible to categorize phosphate rocks into relative rankings of high, medium, or low potential for direct application. Based on agronomic evaluation of phosphate rock from 18 separate deposits around the world, it can be generalized that rocks with citrate-soluble P greater than 17% of the total P can be ranked as having a high potential for direct application. Those with 12%-17% citrate-soluble P would be considered in the medium range while rocks with <12% of the total P being citrate soluble would be expected to perform relatively poorly when compared to the initial crop response possible with conventional fertilizers or the highly reactive phosphate rocks.

Figure 5 illustrates these differences with short-term greenhouse cropping where P had been supplied by a number of rocks from South America. While some rocks performed nearly as well as TSP, a large range in effectiveness can be observed. Depending on soil properties, crop type, and management, finely ground rock with high, medium, and low citrate solubilities generally has effectiveness ranges of 80%-100%, 50%-80%, and 30%-60%, respectively, when compared to the initial crop responses to triple superphosphate (TSP). Recent studies on residual value of phosphate sources show that, even for the low-reactivity rocks which may be considered for direct application use, the initial differences between sources diminish with time. Table 10, in fact, shows that there has been significant response to P but no difference among sources in total yield of brachiaria grass following 4 years of production, despite the fact that yields during the first year followed the levels predicted by citrate solubility. Research has also shown that dustiness, one of the main objectional properties of phosphate rock, can be eliminated without loss of effectiveness when granulated or "minigranulated," as it is called, to a size range of 50- to 150-mesh (Tyler). These minigranules have consistently been shown to perform at or near the effectiveness of powdered rock. In contrast, conventional granulation (6- to 16-mesh [Tyler] granules) substantially reduces the effectiveness of the rock.

Partial Acidulation of Phosphate Rock

In some situations there is a need for a phosphate fertilizer intermediate between directly applied finely ground rock and conventional fully acidulated fertilizers. This need is most apparent in the situation where the reactivity of available phosphate rock is too low to give acceptable short-term yields and where the P-sorption capacity of the soil is high enough to make readily

soluble P fertilizer rapidly unavailable to the plant. Partially acidulated phosphate rock (PAPR) is an alternative which may fill this gap and can be especially important to some developing countries which have rock deposits but only a limited availability of acid for production of conventional fertilizers.

In recent studies it has been observed that phosphoric acid (H_3PO_4) was highly effective in increasing the initial P availability of low reactivity phosphate rocks when using only 10%-20% of the amount necessary to make triple superphosphate (Hammond, Chien, and Polo, 1980). With the Pesca PR from Colombia, for example, 20% acidulation with H_3PO_4 was observed to be 79%-90% as effective as TSP in a greenhouse experiment; whereas, the unacidulated rock was only 10% as effective. With sulfuric acid 40%-50% of the H_2SO_4 required to make single superphosphate may be required to be equally as effective as the material treated with 10%-20% H_3PO_4. It appears promising, however, that fertilizer prepared with less than the conventional quantities of acid can be a highly effective means of supplying P.

CONCLUSIONS

Opportunities for the improvement of the efficiency with which urea is used by the rice crop in developing countries exist. These include mechanical placement, the hand placement of large particles of urea as supergranules or briquettes, and the use of a coating agent such as sulfur. The major problem is the development of a material or mechanical device of value to the millions of small rice farmers in terms of accessibility and economics.

So far as phosphate is concerned the use of indigenous phosphate rock as a direct application material or when processed by both conventional and nonconventional technologies is being actively studied. Only careful agronomic, industrial, and economic evaluations will give the correct routes for exploitation of these phosphate rock deposits, but the potential saving in terms of foreign exchange for many developing countries is such that these studies are a much needed activity.

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Table 1. Fertilizer Consumption and Growth Rates ($N-P_2O_5-K_2O$)

	Consumption				Annual Growth Rates				
	1973/74	1976/77[a]	1977/78[a]	1978/79[b]	1976/77[a]	1977/78[a]	1978/79[b]	1972/73 1977/78	1973/74 1978/79
	million mt				%				
Developed Market Economies									
N	17.85	19.99	19.85	21.29	4.0	-0.7	7.3	3.8	3.6
P_2O_5	14.10	13.39	13.15	14.31	9.2	-1.8	8.8	-0.4	0.3
K_2O	11.48	11.61	11.53	12.58	10.9	-0.7	9.1	1.6	1.8
TOTAL NUTRIENTS	43.43	44.99	44.53	48.18	7.2	-1.0	8.2	1.9	2.1
Developing Market Economies									
N	6.81	8.48	9.58	10.17	15.5	13.0	6.2	8.1	8.4
P_2O_5	3.57	4.52	5.17	5.57	18.6	14.4	7.7	10.3	9.3
K_2O	1.90	2.16	2.57	2.89	22.0	19.0	12.5	9.0	8.7
TOTAL NUTRIENTS	12.28	15.16	17.32	18.63	17.3	14.2	7.6	8.8	8.7
Centrally Planned Economies									
N	14.12	16.56	18.37	19.99	1.3	10.9	8.8	7.5	7.2
P_2O_5	7.67	9.40	9.87	10.63	3.4	1.1	7.7	7.1	6.7
K_2O	7.35	9.32	9.05	9.32	1.9	-2.9	3.0	6.8	4.8
TOTAL NUTRIENTS	29.14	35.28	37.29	39.94	2.0	5.7	7.1	7.2	6.5
WORLD TOTAL[c]									
N	38.78	45.03	47.79	51.44	5.0	6.1	7.6	6.0	5.8
P_2O_5	25.34	27.31	28.19	30.51	8.5	3.2	8.2	3.6	3.8
K_2O	20.73	23.09	23.15	24.79	7.9	0.3	7.1	4.2	3.6
TOTAL NUTRIENTS	84.85	95.43	99.13	106.74	6.7	3.9	7.7	4.8	4.7

a. Revised.
b. Preliminary.
c. Totals may not add due to rounding.

Source: FAO. 1980. Current Fertilizer Situation and Outlook, Commission on Fertilizers, Rome, Italy.

Table 2. Consumption of Fertilizers Per Hectare of Arable Land, 1978/79 (kg/ha)

Regions	N	P_2O_5	K_2O	Total	N	P	K	Total
Developed Market Economies	53.9	36.2	31.9	122.0	53.9	15.8	26.5	96.2
North America	44.5	24.0	25.4	93.9	44.5	10.5	21.1	76.1
Western Europe	98.2	63.2	57.1	218.4	98.2	27.6	47.4	173.2
Oceania	5.4	32.1	5.6	43.2	5.4	14.0	4.7	24.1
Other Dev. Market Econ.	57.3	60.2	43.8	161.3	57.3	26.3	36.4	120.0
Developing Market Economies	16.1	8.8	4.6	29.5	16.1	3.8	3.8	23.7
Africa	3.5	2.8	1.6	7.8	3.5	1.2	1.3	6.0
Latin America	17.6	16.1	10.3	43.9	17.6	7.0	8.6	33.2
Near East	20.4	12.1	0.6	33.1	20.4	5.3	0.5	26.2
Far East	20.9	7.2	4.4	32.5	20.9	3.1	3.7	27.7
Other Dev. Market Econ.	13.4	3.7	2.7	19.9	13.4	1.6	2.2	17.2
Centrally Planned Economies	51.3	27.3	23.9	102.5	51.3	11.9	19.8	83.0
Asia	69.3	19.2	6.1	94.6	69.3	8.4	5.1	82.8
Europe and U.S.S.R.	44.0	30.5	31.1	105.6	44.0	13.3	25.8	83.1
DEVELOPED ALL	49.8	33.9	31.5	115.2	49.8	14.8	26.2	90.8
DEVELOPING ALL	24.1	10.4	4.8	39.3	24.1	4.5	4.0	32.6
WORLD	36.4	21.6	17.5	75.4	36.4	9.4	14.5	60.3

Source: FAO. 1980. Current Fertilizer Situation and Outlook, Commission on Fertilizers, Rome, Italy.

Table 3. Number of Wet and Dry Season INSFFER Experiments and Countries Where Conducted

Country	Number of Experiments: Wet Season	Number of Experiments: Dry Season	Country Total
Sierre Leone	2	1	3
Egypt	1	-	1
Bangladesh	10	4	14
Sri Lanka	5	3	8
India	22	4	26
Indonesia	5	8	13
Korea	3	-	3
Malaysia	2	3	5
Nepal	5	-	5
Philippines	16	10	26
Thailand	7	3	10
	78	36	114

Table 4. Average Agronomic N Efficiency in All INSFFER Experiments and by Planting Season

N Source	Average		
	All	Wet Season	Dry Season
	kg rice/kg N		
Urea Best split	16.6 (94)[a]	13.7 (60)	21.5 (34)
Urea Liquid (plow sole applied)	16.4 (94)	13.5 (60)	20.3 (34)
USG[b]	21.1 (94)	18.5 (59)	23.1 (35)
SCU[c]	23.6 (93)	20.0 (58)	29.3 (35)

a. Number of experiments.
b. Point placed at 10-cm depth.
c. SCU--Sulfur-coated urea, broadcast, and incorporated.

Table 5. Comparison of Rice Yield Responses to Urea and USG or SCU (97 trials in eastern India by the Hindustan Fertilizer Corporation)

Rating of Urea Vs. Modified Urea	USG	SCU
	-% of trials-	
Urea <	55	41
Urea =	38	51
Urea >	7	8

Table 6. Summary of Preliminary Agro-Economic Analysis of 33 N-Efficiency Trials Conducted in Farmers' Fields in Eastern India, 1978 and 1979

N Source	Optimum N Rate	Increased Rice Yield	Net Profit[a] (Rs/ha)	Efficiency	
				Agro. (kg/kg)	Econ. (Rs/Rs)
	kg/ha				
Urea	97	1320	634	13.6	2.50
USG	92	1810	956	19.7	2.94
SCU	86	1760	847	20.5	2.51

a. Assumed prices are: rice = Rs 0.80/kg; Urea-N = Rs 4.35/kg of N; USG-N = Rs 5.35/kg of N; SCU-N = Rs 6.52/kg of N.

Table 7. Summary of Agro-Economic Analysis of 69 Trials in Farmers' Fields, Philippines Wet Season, 1979

N Source	N Rate	Increased Rice Yield	Net Profit[a]	Efficiency Agronomic	Efficiency Economic[a]
	- - - -kg/ha - - - -		- - ₱/ha - -	- -kg/kg-	- - ₱/₱ -
			Economic Optimum Rates		
Urea	120	1,414	1,316 (71.5)	11.8	3.52
SCU	82	1,499	1,416 (77.0)	18.3	3.80
			Selected Rates		
Urea	60	959	986 (53.6)	16.0	4.78
SCU	60	1,308	1,309 (71.1)	21.8	4.35
Urea	98	1,308	1,274 (69.2)	13.3	3.99

a. Assumed prices are: rice = ₱ 1.30/kg; urea = ₱ 4.35/kg of N; SCU = ₱ 6.52/kg of N. Figures in parentheses are US $/acre.

Table 8. Summary of Agro-Economic Analysis of 29 Trials in Farmers' Fields, Philippines Dry Season, 1979/80

N Source	N Rate	Increased Rice Yield	Net Profit[a]	Efficiency Agronomic	Efficiency Economic[a]
	- - - - kg/ha- - - -		- - -₱/ha - -	- -kg/kg-	- -₱/₱- -
			Economic Optimum Rates		
Urea	162	1,990	1,882 (102.3)	12.3	3.67
SCU	109	1,935	1,835 (99.7)	17.8	3.69
			Selected Rates		
Urea	70	1,190	1,243 (67.6)	17.0	5.09
SCU	70	1,610	1,637 (89.0)	23.0	4.59
Urea	101	1,610	1,654 (89.9)	15.9	4.77

a. Assumed prices are: rice = ₱ 1.30/kg; urea = ₱ 4.35/kg of N; SCU = ₱ 6.52/kg of N. Figures in parentheses are US $/acre.

Table 9. Approximate Distribution of Some Suborders of Oxisols, Ultisols, and Inceptisols in Tropical South America and the United States

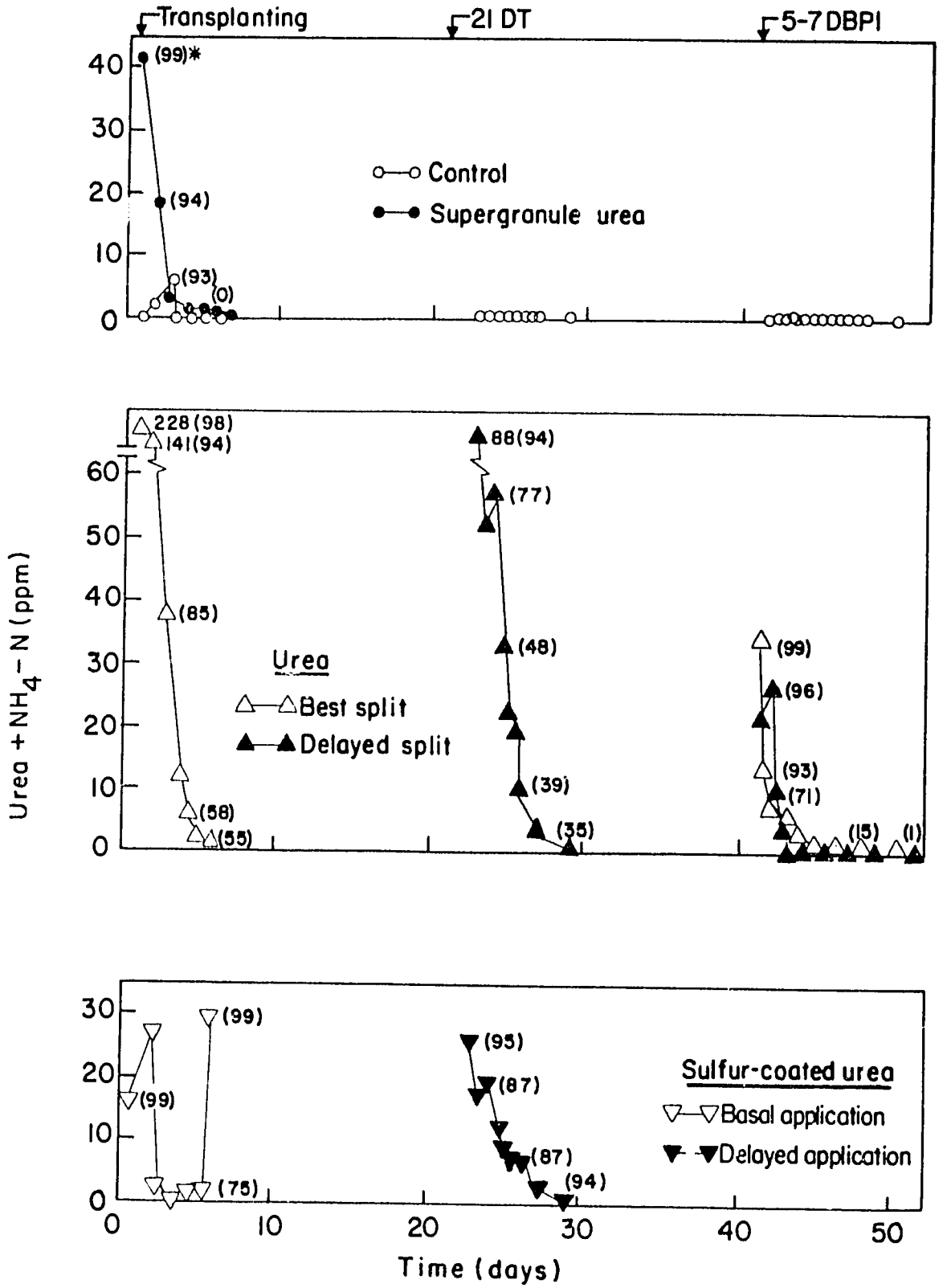
	Area, million ha		% of Total Area	
	South America[a]	United States[b]	South America[a]	United States[b]
Oxisols				
All Suborders	636	0.13	45.3	<0.02
Ultisols				
Aquults	48	11		
Udults, Ustults, and Humults	220	100		
	268	111	19.1	11.9
Inceptisols				
Andepts	32	17		
Tropepts	81	-		
	113	17	8.2	1.9
			72.6	13.8

a. Source: Sanchez, P. A. 1976. Properties and Management of Soils in the Tropics, John Wiley and Sons, New York, New York.
b. Source: U.S. Department of Agriculture (USDA). 1960. Soil Classification: A Comprehensive System, 7th approximation, Soil Conservation Service, Washington, D.C.

Table 10. Effect of Phosphorus Sources and Levels on Relative Yield of Brachiaria Decumbens Grown in the Field on a Carimagua Oxisol, Colombia (Sum of 14 Cuttings)

Phosphorus Source	Relative Yield, %			
	25	50	100	400
	(kg P_2O_5/ha)			
TSP Annual	(33.6)[a]	(35.9)	(37.4)	(45.2)
TSP Residual	100[b] (22.0)	100 (30.6)	100 (32.4)	100 (38.1)
Fosbayovar PR	119	80	102	109
Florida PR	122	94	100	105
Gafsa PR	109	103	104	104
Huila PR	95	113	98	110
Pesca PR	111	81	111	116
Tennessee PR	104	76	95	108
Check (14.4)				

a. Figures in parentheses are dry material yield in tons per hectare.
b. TSP residual considered as 100% at each P rate.



Source: Craswell and De Datta (1979).

Figure 1. Effect of Time and Mode of Urea Application on the Concentration of (urea + NH_4) - N in Floodwater. (IRRI, 1979 Dry Season, *% urea-N).

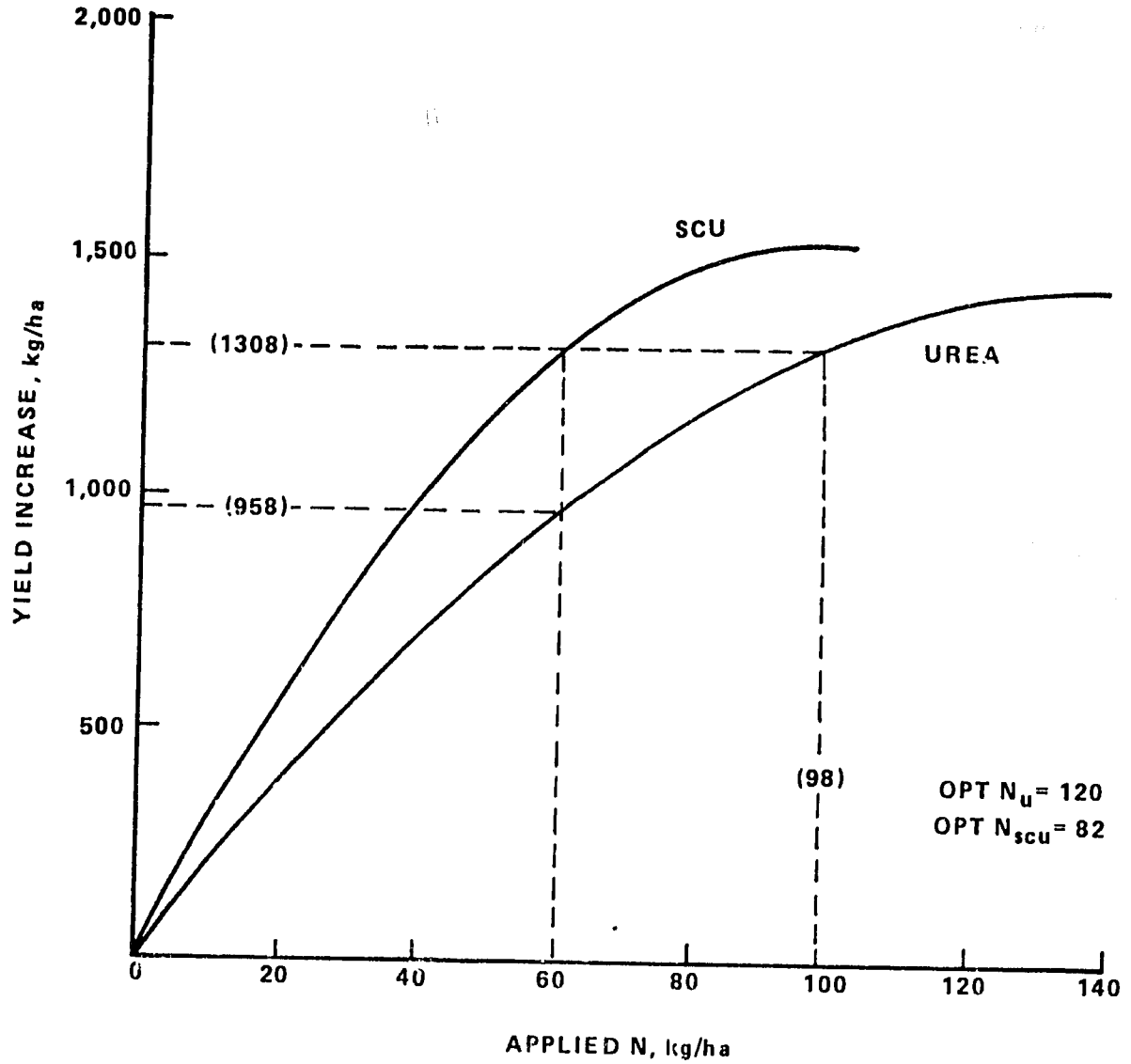


Figure 2. Response of Rice to Urea and SCU in the Philippines (69 trials, 1979 wet season).

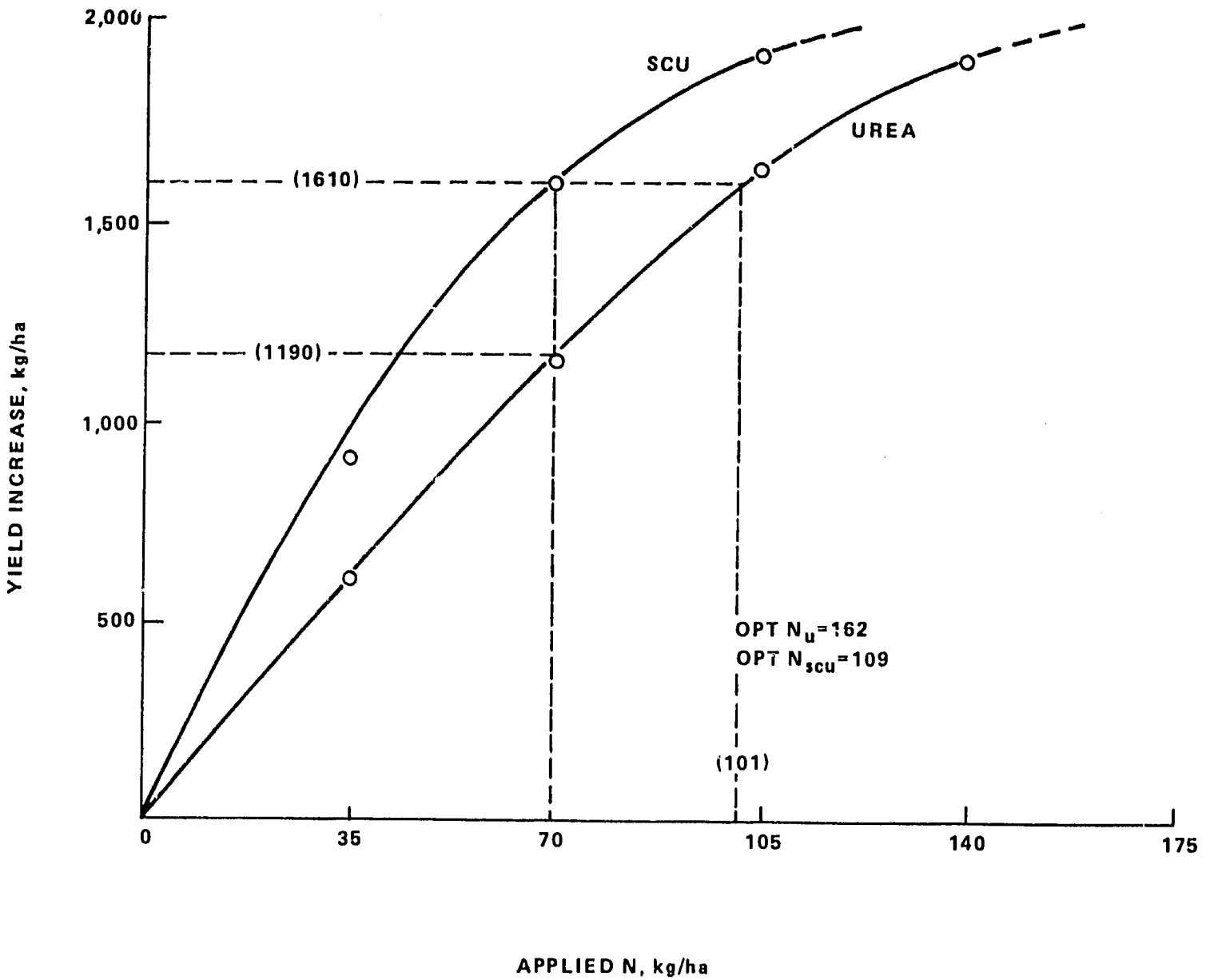


Figure 3. Response of Rice to Urea and SCU in the Philippines (29 trials, 1979/80 dry season).

Figure 4. Locations of 20 Phosphate Deposits in Latin America.

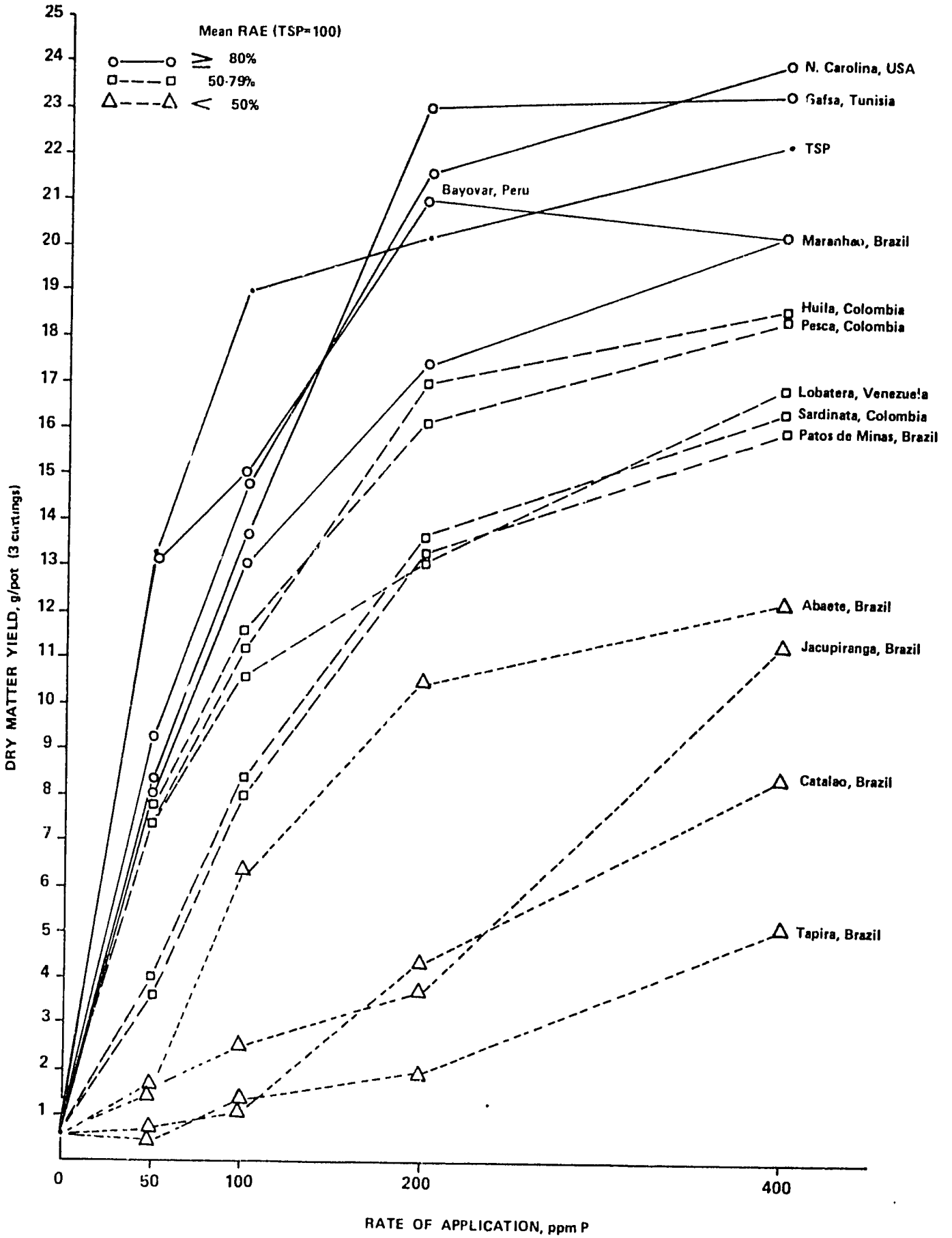


Figure 5. Greenhouse Comparisons of Various Phosphate Rocks Using Maize as the Test Crop.