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This report is a project report covering the period from December 1972 (when the bulletin "Tailoring of Fertilizer for Rice" was issued) through June 1974. The present project is our expansion of the previous project, which was restricted to the use of fertilizer for rice, in that new and improved fertilizers are to be tested on a number of tropical crops. In addition to actual agronomic evaluations of new materials, increased emphasis is placed on developing and demonstrating methods of introducing new fertilizers to farmers so that they will be properly used or they become commercially available.

Additional data has been received from a number of countries pertaining to the use of SCU for rice. In general, these data tend to substantiate those previously reported in that SCU is a superior source of N for rice grain under conditions of intermittent flooding, but that it is no better than conventional sources of N when conditions of intermittent flooding or severe leaching do not exist. A discussion of the commercial potential of SCU in tropical agriculture follows this section.

Insufficient data are available for tropical crops other than rice to warrant any general conclusions at this time.

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Agronomic Research

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Muscle Shoals, Alabama

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SUMMARY

This report is a project report covering the period from December 1972 (when the bulletin "Tailoring of Fertilizers for Rice" was issued) through June 1974. The present project is our expansion of the previous project, which was restricted to the use of fertilizer for rice, in that new and improved fertilizers are to be tested on a number of tropical crops. In addition to actual agronomic evaluations of new materials, increased emphasis will be placed on developing and demonstrating methods of introducing new fertilizers to farmers so that they will be properly used or they become commercially available.

Testing of sulfur-coated urea (SCU) will be expanded to include a number of additional crops, such as sugar cane, corn, cassava cotton, bananas, and cocoa. Additional experiements will be conducted with rice to more precisely define the areas and conditions where the use of SCU will be advantageous and to introduce its use to agricultural workers and industry representatives.

Additional studies are planned with rock phosphate to evaluate its effectiveness for direct applications and to study means of increasing its phosphorous availability by relatively simple methods for local use. Some additional work will be conducted with granulated mixtures of various materials with rock phosphate.

Some preliminary work is contemplated utilizing sulfur coating of multicomponent materials. It is felt that some of these materials may be useful in multiple and intercropping systems, so that nutrients may be applied at a convenient time to become available to succeeding crops as needed.

The need for fertilizers containing secondary and/or micronutrients will be evaluated in several countries where deficiencies are known or suspected, but where no commercial sources of these nutrients are presently available.

Additional data has been received from a number of countries pertaining to the use of SCU for rice. In general, these data tend to substantiate those previously reported in that SCU is a superior source of N for rice grain under conditions of intermittent flooding, but that it is no better than conventional sources of N when conditions of intermittent flooding or severe leaching do not exist. A discussion of the commercial potential of SCU in tropical agriculture follows this section.

Insufficient data are available for tropical crops other than rice to warrant any general conclusions at this time.

POTENTIAL FOR USE OF SULFUR-COATED UREA

The major portion of the agronomic research reported herein deals with the evaluation of SCU (sulfur-coated urea) as a source of nitrogen for rice. These results generally confirm those previously reported by TVA ("Tailoring of Fertilizers for Rice," TVA Bulletin Y-52, December, 1972) in that SCU is a superior source of nitrogen for rice grown under conditions where flooding is delayed or intermittent.

However, the results of some experiments from India and West Africa where rice was grown under conditions where only leaching and not both leaching and dentrification would be expected to occur suggest that SCU may be a superior source of N for rice grown under these conditions as well. In certain parts of the world, large areas of "floating" or deeply submerged rice are grown; very little information relative to N response is available, but in general yields are comparatively low. Further research is planned to evaluate SCU for rice grown under these conditions.

The exact area of rice grown in developing countries under conditions where both leaching and denitrification can occur is difficult to ascertain, but Englestad, et al. ("Tailoring of Fertilizers for Rice," TVA Bulletin Y-52) states that the staff of IRR has estimated that over 75% of the rice in southeast Asia is grown under this type of water management. Preliminary observations suggest that at least 50% (and possibly more) of the rice in West Africa is grown under delayed or intermittent flooding.

According to FAO reports, 131,230,000 hectares of rice were grown in the entire world in 1972. Assuming that 1/3 of this rice was grown under conditions where SCU would be advantageous at locations where N fertilizer is

applied at a rate of 60 kg. N/ha, then approximately 2,600,000 mt of N could profitably be used as SCU. In 1972, 33,700,000 mt of N was used in the world, and these figures suggest that as much as 8% of the world consumption could potentially be expected to be applied as SCU on rice.

On a smaller scale, approximately 114,000 ha of rice are grown in Peru, nearly all of which is grown under conditions where SCU would be the most desirable source of N. Average rice yields in Peru are about 4000 kg/ha, but research by Sanchez and coworkers (see attached report) indicates that with ample N, yields of 9000 kg/ha can be attained. To obtain these yields, 25,500 mt of N as SCU would be needed, compared to 42,000 mt of N as straight urea to obtain the same yield. Thus, SCU would save 16,500 tons of N, or roughly 40% of the N needs.

Results from India indicated that when equal amounts of N were applied, an average of about 1000 kg/ha more grain was produced on experimental plots. This average figure included some areas where SCU was not superior to AS. In 1972, 36,500,000 ha of rice were grown in India, with an average yield of 1616 kg/ha. Proper use of SCU in place of conventional forms probably would not increase yields an average of 1000 kg/ha under farm conditions as it would on the research plots, but an average of 500 kg would be reasonable. This would result in an increase of 18,250,000 mt of rice, an increase of 31% over the 1972 production of 59,000,000 mt.

The above examples are cited to demonstrate the increase in rice production possible through proper use of SCU as a source of N for rice. More research data are needed to more precisely define the conditions under which the use of SCU is advantageous for rice, and to more

precisely evaluate the economics of its use.

Preliminary data indicated that SCU may be a superior source of N for other tropical crops, particularly long-season crops such as sugar cane and pineapply grown in areas of high rainfall.

The results of the wheat experiment followed by sorghum in Pakistan in which the residual effects of SCU were evaluated suggest that in intercropping and multiple cropping systems, fertilizer nitrogen may be applied in a slow-release form (SCU) at a convenient time in the cropping system so that the nutrient elements will be released for utilization by succeeding crops.

Information already obtained indicate that SCU is a superior source of N for crops grown on large enough areas to economically justify its commercial production. As more data are obtained with more crops and from new areas, the potential for its use will undoubtedly increase. Consequently, as adequate supplies become available, programs need to be initiated in selected areas to introduce the use of SCU to agricultural extension workers to the fertilizer industry and to farmers, and to encourage its commercial production. Since the cost per unit of N will always be higher in SCU than in regular urea, the use of SCU will be economically practical only under specific conditions, and these restrictions as to its use make it imperative that effective education and information programs be conducted prior to the commercial introduction of SCU on a wide scale.

BACKGROUND AND OBJECTIVES OF PROJECT

The present project is designed to capitalize on the momentum and knowledge gained in the previous project, "Tailoring of Fertilizers for Rice." This project demonstrated that a superior nitrogen fertilizer can be developed for tropical areas, and that some relatively low cost phosphate sources can be effectively utilized. The present project seeks to broaden the base for development of improved fertilizers through a wider range of agronomic, economic, and engineering evaluations. Previously, the emphasis was placed on SCU as a nitrogen source and the direct application of a limited number of selected phosphate rocks as phosphorus sources for rice fertilization. In this project, a wider range of fertilizer materials will be tested on a variety of upland crops such as maize, wheat, sorghum and sugar cane, cassava, and others of national importance in various countries.

Through its domestic fertilizer research and development program, TVA produces experimental fertilizer materials that may have potential for tropical soil conditions and crops. With support from AID in this project, the capability will exist to work toward improving fertilizers for developing countries through the necessary and logical sequence of production to farmer acceptance to assess the potential for commercial production.

Fertilizers now being used in developing countries, relative economics, and shortcomings of these materials will be evaluated. Experimental products from the laboratories, pilot plants and demonstration scale plants will be submitted to screening tests in greenhouses for comparison with conventional materials; wherever possible, this

screening will be done using soils of the area where the fertilizer will be used. Materials showing potential in greenhouse tests will be further evaluated in actual field programs in selected countries. If successful at this stage, economic and engineering data will be compiled to assess the potential for commercial production. In order to evaluate the product and process, the total system will be studied, including storage, handling and transportation from the point of production to the farm. Information developed throughout this work will be available to industry, foreign and domestic, so that it can develop a production, marketing and use base for utilizing the product. This level of technology is rapidly being achieved for SCU which received major emphasis in the previous study; additional agronomic, economic and engineering data, both with rice and with other crops, will be obtained to complement the previous findings.

This project must be broad and combine a variety of professional disciplines, but it is necessary to retain the flexibility to move forward in specific directions as improvements in products occur. This is necessary to insure that improved products identified in this project can ultimately be made available to farmers regardless of their economic and social status, and that sufficient data are available so that industry can make sound decisions regarding the feasibility for commercial production.

Major objectives of this project are summarized as follows:

(1) Developing fertilizers to meet the nutrient needs of specific tropical crops and soils which are not met economically with conventional fertilizers, or that can meet these needs more economically by increasing the efficiency of fertilizer utilization.

(2) Proving the value of these improved materials to insure that they will increase farmers' income over a large enough area to attract and justify commercial production.

(3) Developing the production technology for new fertilizers as a basis for encouraging and advising potential commercial production. The integrated process designs will seek product quality and economy while striving to minimize harmful emissions to air, water, and land.

(4) Working through cooperating organizations and with leaders in research, extension, and industry to develop and demonstrate methods for introducing new fertilizers to farmers so that they will be properly used when they become commercially available.

SCOPE OF WORK

This project integrates agronomic, economic, and engineering expertise into a single team in order to develop improved fertilizers for a wide range of crops and soils in developing countries. Considerable emphasis is given during the first eighteen months to collecting the data needed to complete the evaluation of sulfur-coated urea and ground rock phosphate for lowland rice. Both materials, then, are scheduled for demonstrations during the latter part of the project in order to educate extension workers and farmers and to attract the fertilizer industry into commercial production. Considerable emphasis is given to the economic evaluation of a total production-marketing-use system for each material in contrast to alternative nutrient sources.

The probability of commercial production of SCU and ground rock phosphate can be enhanced by expanding their use to additional crops and soils. Thus, the project is expanded in scope as compared to the previous project on tailoring of fertilizers for rice in order to test these materials on additional crops.

The expanded work includes a major effort in screening and testing new compounds and forms of fertilizers for various food crops produced under tropical conditions. Although it is already known that more effective and/or less expensive forms of nitrogen and phosphorus are needed, a literature survey will serve as an additional guide to important and pressing fertilizer problems.

Much of the work with fertilizers for both lowland rice and upland crops will consist of field tests in Southeast Asia, Africa, and Latin America. Greenhouse and engineering studies will back up the field research. All field experiments are designed to provide at least an estimate of costs and returns for each fertilizer tested.

PROJECT PLANS FOR FISCAL 1975

In this section, the work for fiscal 1975 will be discussed. It should be remembered that the success of this project depends in a large part upon maintaining sufficient flexibility so that work in individual countries can be adapted to supplement and complement programs already under way. While guidelines and plans of work must be developed so that the objectives of the project are clearly defined, detailed plans for specific countries or groups of countries must be developed by consultation with local cooperators.

These plans will be discussed under the following three general phases of the project:

1. Engineering and development.
2. Agronomic testing and evaluation.
3. Economic evaluations.

Engineering and Development

Phosphate Rock

Methods have been proposed for relatively simple treatment of phosphate rock (PR) to increase the availability of the phosphate to make it more suitable for direct application to the soil. These treatments may be economically feasible in certain areas, especially in view of the current world fertilizer situation. Considerable work has been done at TVA studying means of altering PR, and plans are being developed to initiate further developmental work and field testing of these materials during fiscal 1975.

Emphasis will be placed upon obtaining samples of phosphate rock from deposits in developing countries and testing and improving procedures for increasing their citrate solubility and thus availability of the phosphorus. From this laboratory screening process, several sources will be selected from which small amounts (50 to 100 pounds) will be prepared for greenhouse and field experiments on various soils (as described under agronomic section).

From these results, one or two locations (or countries) will be selected for development of a pilot program to utilize local sources of phosphate rock. This program will involve production of the altered PR and its agronomic evaluation and then educational programs with government and commercial representatives to introduce its use to the farmers.

Sulfur-Coated Fertilizers

Some preliminary work has been done in which urea-potash mixtures were coated with sulfur. The 7-day release rates for the N and K_2O were 17 and 36%, respectively, from the coated product (22-0-11-30S grade). This was the first effort in coating a compound fertilizer with the new coating system.

The widely differing release rates for the nutrients from the coated compound product raise some interesting prospects for "tailoring" the nutrient release rate of sulfur-coated products. It might be possible to cogranulate materials of varying water solubility and sulfur-coat them to produce products with release rates that would approximate the timing of nutrient requirements of the crop. The need for this type of controlled-release product has been mentioned many times by agronomists and may be especially applicable in multiple and intercropping systems.

The possibilities of multicomponent materials for coating are infinite. Perhaps combinations of urea, ammonium sulfate, and ammonium chloride would be of interest. Less soluble materials, such as IBDU, could be included along with the most soluble ones listed above. For multinutrient products, many prospects are evident. Some of these combinations may possibly be too costly for general farm use, but others may possess characteristics which would make them adaptable for use by small farmers in developing countries.

The possibility of granulating phosphate mixtures and possibly sulfur-coating the granules to obtain a slow but adequate release of phosphorus for plants growing in soils which fix large amounts of P will be investigated.

With the present sulfur-coating system utilizing the falling curtain principle in the coating drum, the capability exists for coating granular materials of non-uniform shape. This capability should enhance the feasibility of efficiently coating some of the multimaterial-type products.

Micro- and Secondary Nutrient Materials

Fertiliser materials containing specific secondary and micronutrients will be prepared for use in field testing and evaluation in several countries as the need arises.

Agronomic Testing and Evaluation

Sulfur-Coated Urea

Considerable emphasis will be continued in the evaluation of sulfur-coated urea (SCU). The results cited in this report confirm those given in previous reports and indicate that SCU is a superior source of nitrogen for rice under conditions of intermittent flooding. Some further work with SCU on rice will be conducted (1) to more precisely define the situations where SCU should be used and (2) to acquaint agronomists (research, extension, and industry) in the various countries with this material. As research data accumulate, the second objective will become increasingly important.

Additional studies need to be initiated with other crops grown under conditions where SCU might be a superior N source. Some preliminary results from Hawaii and Florida suggest the use of SCU in sugar cane production may be advantageous.

The varieties of corn grown in some areas of the tropics require 6 to 9 months to reach maturity. A slow-release nitrogen fertilizer might be effective with them, even though SCU has not shown any advantage when applied to corn which matures in 90-120 days. Some experiments are under way to investigate the use of SCU on long-season corn grown under high rainfall conditions.

In certain areas of the humid tropics, improved pastures appear to be the most practical use of the land. In cooperation with North Carolina State University (Tropical Soils Consortium), experiments are under way to evaluate the effectiveness of SCU as a source of nitrogen for tropical pastures, and an extensive series of experiments is planned in cooperation with CATIE at Turrialba.

Preliminary experiments are under way to evaluate the effectiveness of SCB for cassava, under both the 12-month and the 18-month production regimes.

As the program develops, and other areas where SCB may be advantageous are identified, additional experiments will be conducted as local conditions warrant.

TVA will have a demonstration-scale plant capable of producing approximately 10 tons of SCB per hour in operation by early 1976. As soon as this plant is in operation, a wide scale demonstration program to acquaint the agricultural workers and industry representatives with SCB will be initiated. In preparation for this program, additional SCB from the TVA pilot plant will be used in research and demonstration work with government and industry personnel in selected countries so that they will be ready to expand to "full-scale" demonstrations as the SCB demonstration plant comes on stream, and when, as now seems probable, commercial sources of SCB become available.

Below is a partial list of SCB experiments underway or planned for the coming year:

1. Pre-field experiments with paddy, flooding, and both irrigated and nonirrigated upland rice will be conducted in Italy, Costa Rica, Brazil, Ecuador, Panama, Sierra Leone, Ghana, Nigeria, India, Thailand, Pakistan, and Indonesia to more definitely define situations where SCB is superior, and to familiarize local agricultural workers and industry representatives with the material.

2. Sugar Cane--Field experiments are under way or planned in Ghana, Kenya, Peru, and Costa Rica, and other experiments will be initiated in Southeast Asia and Latin America.

3. Upland Crops--Field trials are under way in Ghana, Nigeria, and Sierra Leone with cassava, and with long-season corn in Kenya, Zaire, and Sierra Leone.

4. Pastures--Experiments under way or planned in Costa Rica, Panama, Peru, Brazil, and Sierra Leone.

5. Perennial Crops--For perennial tree crops grown in areas of high rainfall, experiments are planned with bananas, cocoa, coffee, and oil palm in Ecuador and Costa Rica.

Phosphorus

A number of research reports indicate that the P in some deposits of phosphate rock (PR) is relatively available to plants when applied directly to some soils. The PR must be finely ground for maximum effectiveness, and finely ground materials are not convenient either to handle or to apply to the soil. Some finely ground PR materials have been granulated, either PR alone or PR-urea mixtures, but greenhouse tests to date have not been encouraging. Nevertheless, further field studies with granulated materials should be conducted in the tropics before abandoning this line of investigation.

As mentioned before, tests will also be conducted using PR that has been altered so as to increase citrate solubility of the phosphate. These altered materials, together with the original raw phosphate rock, will be compared with soluble phosphate sources in field and

greenhouse experiments on tropical soils, on both strongly acid and on slightly acid or neutral soils. Field experiments are presently under way with raw phosphate rock in Nigeria, Peru, and Brazil. When necessary in order to obtain the needed data, research contracts will be developed with cooperating research institutions such as IITA, CATIE, IRRI, and other experimental stations which have adequate facilities to conduct this type of research.

Considerable interest has again developed in evaluating the effect of soil applications of silicates (usually of calcium or sodium) in reducing the level of phosphate applications needed to obtain optimum yields. But conflicting results have been obtained, so the factors involved need to be more precisely evaluated. A combination greenhouse-field-laboratory project will be developed to be conducted at a location where soils occur which have a high P-fixing capacity; this study lends itself best to a graduate thesis type of investigation.

Secondary and Micronutrients

In developing countries, secondary and micronutrient fertilizers are not generally available, and inadequate data concerning their use are available. These materials (described in Engineering Phase) will be used in field experiments in a number of countries to help determine which of these elements are actually deficient and determine where we need to encourage development of commercial sources of these materials.

Economic Evaluations

While SCU has shown agronomic advantages for rice production in many areas, the economics of its use and production have not been fully worked out. Data are now becoming available so that economic analysis and comparisons with other sources can be made. This will be done first for rice, and then for any other crops for which SCU appears to be advantageous. This will be done under existing prices, input subsidies, etc., that exist in the various countries.

The parameters needed to make economic analyses for the use of SCU need to be defined from the manufacturing plant to the farm where it is to be used. In order to do this, the economics relative to the capital investment required to build an N plant with the facility to produce SCU need to be developed. We also need to develop the costs involved in modifying existing plants to produce SCU, using prilled and/or pan granulated urea.

In each of the three general regions (Africa, Southeast Asia, and Latin America) where data are available or can be developed, economic evaluations of SCU value/cost ratios will be developed. Economic response surfaces for specific crops for SCU will be developed, using data from Nigeria, Ghana, and Sierra Leone in Africa, from Peru, Costa Rica and Brazil in Latin America, and from India, the Philippines, and Indonesia in Southeast Asia. In connection with this, the economists will consult with research institutions in each country cooperating with IFDC to help develop procedures for economic evaluation of SCU and other fertilizers. For Africa and Latin America, economic-engineering cost-analysis data will be developed for importing SCU from sources of supply

from outside the region. For Southeast Asia, the same data will be developed using sources of supply from within Asia (probably Korea, Taiwan, Indonesia, and Philippines).

As work progresses on the use of improved PR from local deposits, the cost factors for this phase of the project will need to be carefully evaluated, since the feasibility of small-volume projects of this type are especially dependent upon local cost structures.

Workshop at Muscle Shoals

Plans are being developed to hold an agronomic workshop and planning session in November at Muscle Shoals with a total of from 15 to 20 participants from cooperating institutions in Africa, Southeast Asia, and Latin America. Current research will be discussed, and plans developed for work to be initiated during the coming season. The participants will also have an opportunity to become acquainted with the programs and facilities of the National Fertilizer Development Center.

Literature Survey

A survey of current and pertinent literature in which various sources of nitrogen and phosphorus have been evaluated using crops grown on tropical soils will help identify possible problems relating to fertilizer use efficiency and at the same time be used to develop some standards for use in evaluating new fertilizer materials. Of particular interest are data relative to nitrogen use efficiency, to phosphate rock availability, and to silica-phosphorus relationships.

It is anticipated that these surveys will be published in bulletin form to be used in planning additional research and as a guide for comparing fertilizer sources until such time as adequate research data are available.

AGRONOMIC RESEARCH

Agronomic research results will be discussed in the following sequence.

1. Research by Overseas Cooperators
   a. Nitrogen Studies
   b. Phosphorus studies
2. Greenhouse Research by TVA at Muscle Shoals

Both field and greenhouse experiments will be discussed in appropriate sections.

Research by Overseas Cooperators

Nitrogen Studies--Rice

Korea--The results from Korea given in tables 1 and 2 are for the 1971 season, but were not received in time to include in the last report on the project "Tailoring of Fertilizers for Rice." The yield data (table 1) show that higher yields were obtained when N was applied as SCU than when applied as urea, even when urea applications were split. Increasing the rate of N applied as SCU resulted in a relatively greater yield increase than when the same rates of N were applied as urea. At each rate of applied N, the uptake of N was greater when SCU was applied than when urea was applied (table 2). No marked differences were noted between the two sources of SCU, although both yields and uptake of N appeared to be slightly higher with SCU-E (dissolution rate between 20.1 and 25.6) than with SCU-C (dissolution rate between 9.1 and 14.6). Precise data concerning water control were not available.

Table 1

Effect of N Source and Rate
On Yield of Two Varieties of Paddy Rice
Korea, 1971

			Yield of Paddy Rice (Mt/ha)			
			Clay Loam Soil		Sandy Loam Soil	
Source of N	Rate of N	Method of Application	Var. 1	Var. 2	Var. 1	Var. 2
Urea	N_1	Basal	6.78	5.80	6.20	6.20
Urea	N_2	Basal	7.13	6.00	7.27	7.27
Urea	N_1	Split	7.06	6.80	7.16	7.16
Urea	N_2	Split	7.26	6.96	7.46	7.46
SCU-C	N_1	Basal	7.24	6.46	7.25	7.25
SCU-C	N_2	Basal	7.45	7.41	7.88	7.88
SCU-E	N_1	Basal	7.48	7.19	7.41	7.41
SCU-E	N_2	Basal	7.41	7.47	8.01	8.01

N_1 = 100 kg/ha for Var. 1, 150 kg/ha for Var. 2.

N_2 = 150 kg/ha for Var. 1, 200 kg/ha for Var. 2.

Var. 1, new short-stemmed variety.

Var. 2, local long-stemmed variety.

*Dissolution Rate between 9.1% and 14.6% in 7 days

**Dissolution Rate between 20.1% and 25.6% in 7 days

Table 2

Effect of N Source and Rate
On Uptake of N by Two Varieties of Paddy Rice
Korea, 1971

			Uptake of N (kg/ha)			
			Clay Loam Soil		Sandy Loam Soil	
Source of N	Rate of N	Method of Application	Var. 1	Var. 2	Var. 1	Var. 2
Urea	N_1	Basal	87	78	74	76
Urea	N_2	Basal	97	79	94	88
Urea	N_1	Split	111	93	100	90
Urea	N_2	Split	117	107	119	97
SCU-C	N_1	Basal	125	96	112	95
SCU-C	N_2	Basal	150	131	144	124
SCU-E	N_1	Basal	130	118	122	121
SCU-E	N_2	Basal	156	144	150	141

N_1 = 100 kg/ha for Var. 1, 150 kg/ha for Var. 2.

N_2 = 150 kg/ha for Var. 1, 200 kg/ha for Var. 2.

Var. 1, new short-stemmed variety.

Var. 2, local long-stemmed variety.

India--The results of four experiments conducted with flooded, transplanted rice in India by the All-India Coordinated Rice Project, Hyderabad, are given in table 3. The response to N was excellent, the yield without N being only 41% of those obtained with basal applications of N as urea. With basal applications of SCU, the yields were 20% higher than with basal applications of urea, and, in the three experiments in which urea applications were split, yields with SCU were 18% higher than yields with split applications of urea. When comparing the average N-response (kg grain/Kg N), yields were increased 1/3 more by SCU than by basal applications of urea.

The data from one experiment with light irrigated rice in India are given in table 4; yields were relatively low, and differences between N sources or method of application were not significant. However, yields with SCU tended to be higher than when all urea was applied at planting, but lower than when split applications of urea were applied. Again, yields were increased more than 1/3 more with SCU than with basal applications of urea.

In tables 5 and 6, the yields of a short-duration, transplanted rice grown in irrigated light-textured soils at five locations in India indicate that higher yields were obtained with SCU than with urea when applied as a basal application. Yield increases due to basal N applications were 50% greater with SCU than with urea. However, split applications of urea resulted in yields equal to those obtained with basal applications of SCU.

The yields of direct-seeded upland rice grown at three locations in India are given in table 7, and the relative yields in table 8. Yields were low due to drought, but good responses were nevertheless obtained for

Table 3

Effect of N Source and Time of Application on Yield of Paddy (Flooded) Rice in India, 1972. (Summary of Reported Data from 4 Experiments)

Experimental Number and Season	Source of Nitrogen	Rate of N kg/ha.	Method of Application	Yield mt/ha.	Relative Yield %	N-Response Kg Grain/ Kg N
	-	-	-	1.96	34	-
	Urea	120	Basal	5.73	100	31.4
1.1	Urea	120	80 + 40	6.11	107	34.5
Rabi	SCU	120	Basal	7.13	124	43.0
1.2	-	0	-	2.02	30	-
	Urea	125	Basal	6.82	100	38.4
Rabi	Urea	125	35 + 20 + 35 + 35	6.33	95	34.4
	SCU	125	Basal	7.81	115	46.3
1.3	-	0	-	1.68	44	-
	Urea	100	Basal	3.85	100	21.7
Kharif	Urea	100	30 + 20 + 25 + 25	4.00	104	23.2
	SCU	100	Basal	4.62	120	29.3
1.4	-	-	-	3.55	55	-
	Urea	125	Basal	6.50	100	23.6
Rabi	SCU	125	Basal	7.81	120	34.1

Table 4

Effect of N Source and Time of Application on Yield of Light Irrigated Rice in India, 1972. (Summary of Reported Data From One Experiment at Pattambi)

Experimental Number and Season	Source of Nitrogen	Rate of N (kg/ha.)	Method of Application	Yield (mt/ha.)	Relative Yield (%)	N-Response Kg Grain/ Kg N
3.8		0	-	2.04	85	-
Rabi	Urea	120	Basal	2.41	100	3.08
	Urea	120	60 + 0 + 30 + 30	2.67	111	5.25
	SCU	120	Basal	2.55	106	4.25

Table 5

Effect of N Source and Time of Application on Yields of Short-Duration Transplanted Rice Variety Grown on Irrigated Light-Textured Soils at 5 Locations in India, 1972
(Summarized From Reported Data)

Source of N	Rate of N kg/ha	Method of Application	Grain Yields (Mt/Ha)						Average N-Response Kg Grain/ Kg N
			Faizabad	Karjat	Mandya	Pattambi	Raya	Average	
-	-	-	2.91	2.66	2.11	1.94	3.40	2.60	-
Urea	100	Basal	3.86	4.07	3.61	2.85	4.82	3.84	12.4
Urea	100	50 + 25 + 25	3.99	4.30	4.34	3.34	6.42	4.48	18.8
SCU	100	Basal	3.68	4.68	4.39	3.60	5.72	4.41	18.1

Table 6

Effect of N Source and Time of Application on Relative Yields of a Short-Duration Transplanted Rice Variety Grown on Irrigated Light-Textured Soils at 5 Locations, India, 1972
(Data Calculated From Table 5)

Source of N	Rate of N kg/ha	Method of Application	Relative Yield (%)					
			Faizabad	Karjat	Mandya	Pattambi	Raya	Average
-	-	-	75	65	54	60	71	67
Urea	100	Basal	100	100	100	100	100	100
Urea	100	50 + 25 + 25	103	106	120	117	133	116
SCU	100	Basal	95	115	122	126	119	115

Table 7

Effect of Source and Time of Application of N on Yields of Direct-Seeded Upland Rice at 3 Locations in India During Kharif, 1972

Source of N	Rate of N Kg/Ha	Time of Application	Yield of Grain (Mt/Ha)			
			Borhampur	Pattambi	Faizabad	Average
-	0	-	1.37	0.21	1.06	0.60
Urea	60	Basal	1.66	1.53	1.57	1.59
Urea	60	30 - 0 - 30 - 0	2.24	2.05	1.71	2.00
SCU	60	Basal	1.85	1.67	1.29	1.54

Table 8

Effect of Source and Time of Application of N on Relative Yields Of Direct-Seeded Upland Rice at 3 Locations in India During Kharif, 1972 (Data Calculated from Table 6)

Source of N	Rate of N Kg/Ha	Time of Application	Relative Yield (%)			
			Borhampur	Pattambi	Faizabad	Average
-	0	-	83	14	68	55
Urea	60	Basal	100	100	100	100
Urea	60	30 - 0 - 30 - 0	135	134	109	126
SCU	60	Basal	111	96	82	96

N applications. No differences were noted between yields obtained with band applications of urea and SCU, but highest yields were obtained with split applications of urea.

The effect of source and time of N application on rice grown under waterlogged conditions is given in tables 9 and 10. Higher yields were obtained using SCU than urea when both were all applied at planting (band)), and the yield increase due to N applications was 36% greater with SCU than with urea. However, split applications of urea were as good, and possibly slightly better, than band applications of SCU.

The results of the various experiments in India are summarized in the following table.

		Relative yield increase*(%)			
		Kind of rice and number of locations**			
Source of N	Method of Application	Flooded (3)	Irrigated (4)	Upland (2)	Waterlogged (4)
Urea	Band	100	100	100	100
Urea	Split	103	150	150	152
SCU	Band	132	147	93	136

*Calculated from increase over check, assuming increase for band-applied SCU equal to 100%.
**Data from tables 3 4 & 6 8 10

These studies are in general agreement with previous results ("Reshoring of Fertilizers for Rice," FFA Bulletin F-32, 1972) in that SCU is generally a superior source of N for rice grown under moisture regimes where alternate oxidizing and reducing conditions may develop

Table 9

Effect of N Source and Time of Application on Yield of Waterlogged Rice
At Six Locations in India, Kharif, 1972

Source of N	Rate of N	Method of Application	Yield of Rice (Mt/Ha)							Average N Response Kg Grain/ Kg N
			Akulhurai	Agartala	Bapatla	Gograghat	Nawabganj	Sambalpur	Average	
-	0	-	2.51	2.89	2.40	1.39	3.43	3.19	2.66	-
Urea	100	Basal	3.82	3.64	3.91	2.06	3.98	5.36	3.76	11.2
Urea	100	50 - 25 - 25	3.97	4.53	3.73	2.60	3.63	7.64	4.25	17.1
SCU	100	Basal	4.08	4.79	4.03	1.86	3.76	6.53	4.36	15.2

Table 10

Effect of N Source and Time of Application on Relative Yield of Waterlogged Rice at Six Locations
In India, Kharif, 1972 (Data Calculated from Table 8)

Source of N	Rate of N	Method of Application	Relative Yield of Rice						
			Akulhurai	Agartala	Bapatla	Gograghat	Nawabganj	Sambalpur	Average
-	0	-	66	79	63	68	96	57	71
Urea	100	Basal	100	100	100	100	100	100	100
Urea	100	50 - 25 - 25	104	124	95	127	102	137	115
SCU	100	Basal	105	132	103	91	105	117	109

in the soil. SCU may or may not result in better yields than soluble N fertilizers which are applied in split applications, but split applications may not be either economical or practical under many conditions. More precise information is needed about the moisture regimes under which these experiments were conducted before a final evaluation of the results is made.

Liberia--The results of one experiment with direct-seeded, flooded rice (table 11) are not conclusive since the response to N fertilizer was low. Yields with basal applications of SCU tended to be higher than with basal applications of urea, but split applications of SCU were no more effective than the urea treatments.

In 17 demonstrations on upland rice, highest average yields were obtained with SCU (table 12), but the overall results were too variable to allow any conclusions to be drawn. The possibility of sulfur response must also be considered, since CSP was used as a source of P, and indications are that the rate of P might not have been sufficient for maximum yields.

Sierra Leone--The yields from five locations in Sierra Leone are given in table 13. While few statistically significant differences were noted, there was a general tendency for yields to be higher when SCU was applied than when ammonium sulfate (AS) was applied. However, responses to N or to rates of N were not large, so significant differences between N sources were not expected.

At three of the above locations, identical experiments were conducted to compare various rates of AS and SCU, and an additional treatment at the highest rate of N was included with a higher rate of P (table 14). The results indicate that 22 kg P/ha was not adequate for maximum yields. At every rate of P, higher average yields were obtained with SCU than with AS, and this difference was highly significant when all yields from all three locations were considered.

Table 11

Effect of N Source and Method of Application on Direct Seeded, Flooded Rice in Liberia in 1973

Source of N	Rate of N kg/ha	Method of Application	Yield mt/ha	Relative Yield
-	0	-	3.20	85
Urea	100	Basal	3.76	100
Urea	100	Basal + 2 topdressings	3.70	98
SCU	100	Basal	4.06	108
SCU	100	Basal + 2 topdressings	3.60	97

Table 12

Average Results from 17 Demonstrations on Direct-Seeded Upland Rice on Poorly-Drained Soils in Liberia

Fertilizer Treatment $N + P_2O_5 + K_2O$ (kg/ha)	Source of Nitrogen	Yield kg/plot	Relative Yield (%)
0 + 0 + 0	-	102	82
0 + 20 + 0	-	142	115
20 + 20 + 0	Urea	124	100
40 + 20 + 0	Urea	116	94
20 + 0 + 0	Urea	116	94
20 + 40 + 0	Urea	133	107
40 + 40 + 0	Urea	127	102
20 + 20 + 0	SCU	152	123

Table 13

Effect of N Source on Yield of Rice at Five Locations in Sierra Leone in 1973. All Nitrogen was Applied as a Basal Applicator at Time of Planting

Source of N	Rate of N kg/ha	Yield of Rice (mt/ha)				
		Mangrove Swamp Rokpur	Inland Swamps		Irrigated Mange	Boli Koniobe
			Njala	Kenema		
=	0	1.83	2.54	3.92	4.52	1.71
AS*	34	2.17	3.77	4.11	4.30	1.69
	67	2.19	3.42	3.48	5.24	1.72
SCU	34	2.47	3.69	4.80	4.41	1.34
	67	2.44	3.90	4.47	4.80	2.05
	50	2.57	3.19	4.50	4.70	1.99
	100	3.11	4.18	4.36	5.34	1.85
LSD	0.05	0.41	ns.	ns.	ns.	ns.
	0.01	0.56	ns.	ns.	ns.	ns.
CV	%	11.5	13.0	15.5	12.1	24.2
Level of Sign:						
SCU vs. AS	=	ns.	n.s.	ns.	ns.	ns.

*AS: ammonium sulfate

Table 14

Effect of N Source on Yield of Rice Grown in Swamps at Three Locations in Sierra Leone in 1973. All N and K Applied at Planting

		Yield of Rice Grain (mt/ha)			
			Inland Swamps		
Source of N	Rate of N-P kg/ha	Mangrove Swamp Rokpur	Njala	Kenema	Average
AS*	34-22	2.20	2.79	3.23	2.74
	50-22	1.96	2.68	3.45	2.69
	67-22	2.47	2.73	3.34	2.84
	67-45	2.67	2.81	3.96	3.15
SCU	34-22	2.47	2.90	3.96	3.11
	50-22	2.54	3.04	4.48	3.35
	67-22	3.02	3.41	3.63	3.35
	67-45	3.09	3.72	4.96	3.92
LSD = 0.05	=	0.51	ns.	ns.	0.70
0.01	=	0.69	ns.	ns.	0.94
CV %	=	13.5	27.4	30.3	27.3
Level of Sign:					
AS vs. SCU	=	0.01	ns.	ns.	0.01

*Ammonium sulfate

These results indicate that under the moisture regimes prevailing in the rice-growing areas of Sierra Leone where these experiments were located, SCU is superior to AS as a source of N.

Ghana--In two experiments with upland rice--one rainfed and one irrigated--in Ghana (table 15), yields with SCU were lower than those with ammonium sulfate (AS). Apparently, the successive anaerobic and aerobic conditions under which SCU is a superior N source did not occur in these experiments. In another experiment in Ghana (table 16), grown under conditions of poor water control, higher yields were obtained with SCU than with either urea or AS, and yields obtained with urea tended to be lower than those obtained with AS.

Nigeria--The results of two experiments located at the International Institute of Tropical Agriculture (IITA) in Nigeria are given in table 17. No significant differences were noted between yields obtained with SCU and those with AS in either experiment, although yields tended to be higher when AS was applied in the first season and when SCU was applied in the second season. In both experiments, urea appeared to be inferior to both SCU and AS. Water control in these experiments was good.

Peru--A summary of several years' work with SCU in Peru has been published in a paper entitled "Performance of Sulfur-Coated Urea Under Intermittently Flooded Rice Culture in Peru" by P. A. Sanches, A. Gavidia O., G. E. Ramires, R. Vergara, and F. Minguillo (Soil Science Society of America Proceedings, 37:789-792, 1973). A copy of the paper is attached to this report, and an abstract of their results follows.

Table 15

Effect of N Source and Method of Application on Yield of Upland Rice (Atebubu) and Irrigated Rice (Binduri) in Ghana

Source of N	Rate of N kg/ha	Method of Application	Yield of Rice (mt/ha) Atebubu	Yield of Rice (mt/ha) Binduri
-	0	-	1.14	1.98
AS	72.6	Basal	2.47	3.34
AS	72.6	36.3 + 36.3	2.75	3.32
SCU	72.6	Basal	1.87	3.02
LSD	0.05		0.42	0.51
	0.01		0.56	0.69

Table 16

Effect of N Source and Rice on Yield of Rice Grown in Ghana Under Conditions of Poor Water Control. 1973

Source of N	Yield of Rice (mt/ha) Rate of Nitrogen (kg/ha) 45	90	135	Average
Urea	2.66	3.31	2.90	2.96
AS	2.74	3.72	4.59	3.68
SCU	3.47	4.37	5.02	4.29
Average	2.96	3.80	4.17	

Table 17

Effect of N Source and Rate on Yield of Flooded Rice in Nigeria (IITA)
All Fertilizer is Broadcast and Incorporated Into Soil One
Week Before Planting, Plots Irrigated for
Two Weeks After Planting and Then Flooded. 1973

Source of N	Rate of N (kg/ha)	Yield of Rice (mt/ha) First Season (1/8 - 5/10)	Yield of Rice (mt/ha) Second Season (5/22 - 9/25)
-	0	2.93	2.05
AS	37.5	5.41	4.19
AS	75.0	4.77	4.54
AS	150.0	5.11	4.53
Urea	75.0	3.29	3.83
SCU-C	75.0	4.41	5.51
SCU-D	75.0	4.21	3.65
SCU-F	75.0	4.23	4.92
LSD	0.05	1.18	1.72

Table 18

Yield of Basmati-370 Rice at Punjab Agricultural Research Institute in Pakistan in 1969-70 Grown Under Conditions of Intermittent Flooding

Rate of application (Kg/ha)		Source of N	Yield (mt/ha)	Yield Increase Due to N (mt/ha)
N	P_2O_5			
0	0	-	2.12	-
67	67	AS	2.45	0.33
100	100	AS	2.74	0.62
67	67	Urea	2.60	0.48
100	100	Urea	2.97	0.85
67	67	SCU	3.15	1.03
100	100	SCU	3.25	1.12

Average for Sources:

	Yield		Yield Increase	
	Mt/ha	Relative (%)	Mt/ha	Relative (%)
AS	2.60	93	0.48	72
Urea	2.79	100	0.67	100
SCU	3.20	115	1.08	161

"Short-statured, high yielding rice varieties grown extensively in northern Peru require extremely high rates of conventional N sources to achieve maximum yields. The recovery of applied N is extremely low due to the use of intermittent flooding. This water management system results in heavy N losses even with properly timed split applications. In search of simpler and more effective methods of N management, eight field experiments were conducted in the region to evaluate sulfur-coated urea (SCU), an experimental, slow-release N source supplied by the Tennessee Valley Authority. Rice yields were increased an average of 59% more by pretransplant-incorporated SCU than by urea or ammonium sulfate applied in the same manner. SCU produced excessive vegetative growth which resulted in yield reductions at high N rates."

"Regardless of an assumed 48%-higher unit N cost in SCU, the overall benefits of pretransplant-incorporated applications of SCU were favorable since there was a decrease of 40% in the optimum rate of N and the need for precise timing of application was eliminated."

Pakistan--In Pakistan, basal applications of AS, urea, and SCU to rice grown under conditions of intermittent flooding in 1969-70 (table 18) indicate that SCU is a superior source of N as compared to urea or AS when all N is applied at or before planting. The data also indicate that a yield response was obtained for P applications; but a comparison of N sources at each level of P indicates that no interaction between N and P was present, so that differences between N sources were relatively the same at each level of P. Yields were increased about 60% more when SCU was applied than when urea was applied. Yield increases with AS were only about 72% of the increase obtained with urea; these results do not agree with the generally-reported superiority of AS as compared to urea as a source of N for rice.

In 1973, experiments were conducted in Pakistan using both Basmati-370 and IRRI-6 varieties of rice grown under conditions of intermittent flooding (table 19). When all N was applied at puddling, or 1/2 at puddling and 1/2 at panicle initiation, both AS and SCU were superior to urea, with SCU tending to be the most efficient source. However, when N was applied 1/2 at transplanting and 1/2 at panicle initiation, SCU was the poorest source of N. This would indicate that the release of N from SCU applied at these times is too slow for optimum plant growth.

In another experiment in Pakistan in 1973, no differences in the effectiveness of urea, AS, or SCU were noted in the yields of continuously-flooded rice (table 20). Again, these results are consistent with earlier results which indicate no superiority for SCU when rice is continuously flooded.

Nitrogen Studies--Maize

A series of three experiments were conducted by IITA in Nigeria in 1972-73 comparing AS, urea, SCU, and CAN (calcium ammonium nitrate) as sources of N for maize (table 21). A significant yield response was obtained for N at each location, but no consistent differences were noted among sources. These results are consistent with results at other locations which have not shown that SCU is a superior source of N for maize grown over a period of 3 to 4 months.

Nitrogen--Wheat

The yields of wheat in Pakistan in 1969-70 (tables 22 and 23) show that yields with SCU tended to be lower than those with urea, although at one location where sorghum was grown following wheat with

Table 19

Yields of Basmati-370 and IRRI-6 Rice at Punjab Agricultural Experiment Station in Pakistan in 1973 Under Conditions of Intermittent Flooding

Source of N	Rate of N B-370	Rate of N IRRI-6	Time of Application	Yield (Mt/ha) Basmati-370	Yield (Mt/ha) IRRI-6	Yield (Mt/ha) Average	Yield Increase (Mt/ha)
-	0	0	-	2.21	3.53	2.87	-
SCU	90	150	At Puddling	3.25	5.45	4.35	1.48
Urea	90	150	At Puddling	3.09	5.00	4.05	1.18
AS	90	150	At Puddling	3.24	5.29	4.27	1.40
SCU	90	150	½ Puddling; ½ Panicle Initiation	3.72	5.72	4.72	1.85
Urea	90	150	½ Puddling; ½ Panicle Initiation	3.35	5.02	4.19	1.32
AS	90	150	½ Puddling ½ Panicle Initiation	3.53	5.29	4.41	1.54
SCU	90	150	½ After Transplanting ½ Panicle Initiation	3.12	5.62	4.37	1.50
Urea	90	150	½ After Transplanting ½ Panicle Initiation	3.40	6.24	4.82	1.95
AS	90	150	½ After Transplanting ½ Panicle Initiation	3.49	5.83	4.66	1.79

All plots received 45 lbs. P_2O_5/acre as single superphosphate

Source of N	Relative Yield Increase (%) At Puddling	½ Puddling, ½ Panicle	½ Transplant, ½ Panicle
Urea	100	100	100
AS	119	117	92
SCU	125	140	77

Table 20

Yield of Continuously Flooded Rice as Affected by Rate and Sourc. of Nitrogen in 1973 at the Government Rice Research Institute, Kala Shah Kaku, Pakistan

	Yield of Rice (Mt/ha) at Different Levels of Nitrogen Fertilizer (kg/ha)				
Source of N	0	56	112	224	Mean (Less 0 Rate)
Urea	3.20	5.80	5.99	5.14	5.64
AS	3.69	5.88	5.60	5.12	5.53
SCU	3.06	5.52	5.88	5.07	5.49
Urea + S	3.48	5.96	5.86	4.90	5.57
Mean	3.36	5.79	5.83	5.06	

Table 21

Effect of N-Sources and Rates on Yield of Maize at IITA (Egbeda and Apomu soil series) and at Ikenne (Alagna Soil Series)

N-Source	N-rate (kg/ha)	Apomu Series	Egbeda Series	Alagba Series	Mean
			(kg/ha)		
Check	0	4205	5953	2392	4184
Ammonium Sulfate	60	5150	7501	3586	5412
Ammonium Sulfate	120	5519	7417	3668	5535
Urea	60	5193	7230	3905	5443
Urea	120	5549	7297	3307	5384
Sulfur-coated urea C	60	4810	6991	3410	5070
Sulfur-coated urea C	120*	5229	6994	3760	5384
Calcium amm-nitrate	60*	5657	7966	3386	5670
Calcium amm-nitrate	120*	5346	7170	3280	5265
Urea-ammonium sulfate	60	5307	6204	3769	5093
LSD 0.05		801	1182	742	

* Treatments added in 1973 to Apomu and Egbeda soil series.

Table 22

Yield of Wheat at Punjab Agricultural Research Institute in Pakistan in 1969-70. All Nitrogen Applied At Wheat Seeding.

Source of N	Rate of N Kg/ha	Yield (Mt/ha)
-	0	2.40
Urea	56	3.07
Urea	112	2.90
Urea	168	3.05
SCU-1	56	2.37
SCU-1	112	2.85
SCU-1	168	2.70
SCU-2	56	2.67
SCU-2	112	2.27
SCU-2	168	2.44

Average of 3 rates of N for each source:

Urea = 3.01
SCU-1 = 2.64
SCU-2 = 2.46

no further nitrogen applications (table 23), higher yields were obtained in the plots where SCU had been applied for wheat. This suggests some interesting possibilities for multiple and intercropping systems--in such systems perhaps slow release fertilizers can be applied at a convenient time in the cropping system and the nutrients released for uptake by succeeding crops.

Phosphorus--Rice

Some greenhouse and field studies evaluating phosphate rocks as source of P for rice have been conducted. The results obtained relating the citrate solubility of phosphate rock to response by flooded rice in greenhouse studies at TVA and in the field in Thailand are summarized below. A copy of a paper entitled "Response by Flooded Rice to Phosphate Rocks Varying in Citrate Solubility," by O. P. Engelstad, A. Jugsujinda, and S. K. DeDatta, published in Soil Sci. Soc. Am. Proc. 38:524-529, 1974 is also attached to this report.

Studies were conducted in the greenhouse and in the field to evaluate several phosphate rocks for flooded rice. A close relationship was found to exist between rice yield response to applied P and citrate solubility in a series of phosphate rocks representing the theoretical range in this parameter. Greenhouse (TVA) and field data (Thailand) showed quite similar results in this respect.

A procedure is presented which enables one to make the choice of P source on the basis of both agronomic effectiveness and prices of P in triple superphosphate (TSP) versus phosphate rock.

Residual data are presented which show the same general pattern of effectiveness among sources through the second crop as found for the first crop. The residual effectiveness of TSP remained higher than that of the phosphate rocks; however, the relationship between initial citrate solubility of the phosphate rocks and relative effectiveness in the second crop was rather poor.

Table 23

Yield of Wheat Succeeded by Sorghum as Affected by Nitrogen Fertilizers Applied at Wheat Planting at Punjab Agricultural Research Institute in Pakistan in 1969-1970

Source of N	Rate of N (Kg/ha)	Yield (MT/ha) Wheat	Yield (MT/ha) Sorghum*
-	0	1.14	12.9
Urea	56	2.56	13.0
Urea	112	3.39	18.3
Urea	168	3.94	19.1
SCU-2	56	1.51	17.5
SCU-2	112	1.94	21.3
SCU-2	168	2.28	25.1
SCU-1	56	1.76	19.3
SCU-1	112	2.31	19.9
SCU-1	168	2.80	25.2

*Planted to measure residual effect of N applied to preceding wheat crop. Green fodder yields (not dry weight).

Average for sources:

	Wheat	Sorghum
-	1.14	12.9
Urea	3.30	16.8
SCU-2	1.91	21.3
SCU-1	2.29	21.5

Greenhouse and field data show clearly that there are substantial differences among phosphate rocks in terms of agronomic effectiveness. Further, these differences can be predicted by means of citrate solubility or by the ACS (Absolute Citrate Solubility) index. It appears that the latter is more appropriate where the content of apatite varies among phosphate rocks. The most soluble phosphate rocks approached but did not actually equal TSP in limiting (maximum) yield in these experiments, regardless of rate applied. One needs to consider the definite possibility of some yield loss in choosing a phosphate rock over TSP; such yield losses must be weighed against the lower price of phosphate rock. The explanation for such losses may involve concentration of soluble P in the soil. If P concentration is limiting or inadequate because of a lower dissolution rate of phosphate rock, the growth rate and ultimate yield will be diminished accordingly.

The RAE (Relative Agronomic Effectiveness) values based on yield increases reflect the agronomic effectiveness of these various sources relative to the TSP standard; however, these should be supplemented by an economic analysis before rational choices can be made.

The following calculations will provide an estimate of the Relative Economic Effectiveness (REE):

$$REE = \frac{Y_{PR}}{Y_{TSP}} * \frac{P_{TSP}}{P_{PR}} * 100$$

or

$$REE = RAE * \frac{\text{Price of TSP/kg P}}{\text{Price of PR/kg P}}$$

If RAE exceeds 100 in this calculation, the phosphate rock would be preferable to TSP.

There are indications that if the P in the more soluble phosphate rocks (North Carolina, north Florida, central Florida) is less than half as expensive as that in TSP, these rocks would be feasible alternatives to TSP on soils similar to those used in Thailand.

This analysis does not take into account the possibility of lower yields from use of phosphate rock. It could be argued that at less than maximum yields, TSP would produce a certain yield at lower rates of P than would phosphate rock. This would especially be true for low rates of application. For example, at Klong Luang, 5500 kg of rice per hectare could have been produced with either 11 kg of P as TSP or 44 kg of P as some of the more reactive phosphate rocks. It should be pointed out, however, that this is the yield level that would show the widest difference; such is the advantage of hindsight.

Farmers generally prefer granular fertilizers for machine or hand application. This is a disadvantage for the phosphate rocks, which are normally applied in finely divided form.

Further studies were conducted at TVA using granulated mixtures of urea and phosphate rock. These greenhouse experiments were conducted to determine the effectiveness of granulated mixtures of urea and phosphate rock (PR) and granulated, partially acidulated PR as sources of P for flooded rice. The urea-PR products were rather poor sources of P, varying between 1% and 53% as effective as granular triple superphosphate (TSP). Some increase in effectiveness in these urea-PR products was obtained from post-flood stirring to simulate the puddling of rice paddies before seedling transplanting.

The partially acidulated, granulated PR products were intermediate in effectiveness between urea-PR and TSP. However, in no case were they more than 58% as effective as TSP. No significant granule size effects were found for these products. Finely divided PR (-100 mesh) was generally more effective than the granular PR products, ranging from 30% to 86% as effective as TSP.

However, it is felt that some further field experiments with these materials and other types of granulated mixtures are warranted before concluding that they have no agronomic potential. In addition, as stated under the section on "Engineering and Development," further experiments with raw rock phosphate and with rock phosphate treated to enhance citrate solubility are to be conducted.

Phosphorus--Maize

Another series of three experiments was conducted by IITA in Nigeria comparing TSP, AOP, APP, and PR at one location (table 24). No definite conclusions can be drawn from these results since only one year is involved; however, they do suggest that further work with PR is warranted on these soils.

Table 24

Effect of P Source and Rate on Yield of IITA Maize Composite AxB at IITA (Egbeda and Apomu soil series) and at Ikenne (Alagba soil series) 1973

P-Source	Rate of P kg/ha	Apomu S Series	Egbeda Series	Alagba Series
	(kg/ha)			
Control	0	2954	2419	3343
Triple superphosphate	20	3629	3378	3799
Triple superphosphate	40	4009	3884	4105
Triple superphosphate	60	4277	4386	4225
Ammonium-orthophosphate	20	4201	4124	4080
Ammonium-orthophosphate	40	4270	4706	4237
Ammonium-polyphosphate	20	4036	4246	3796
Ammonium-polyphosphate	40	4431	4996	4096
N. Carolina rock-phosphate	20	-	3594	-
N. Carolina rock-phosphate	40	-	4216	-
Morocco rock-phosphate	20	-	3634	-
Morocco rock-phosphate	40	-	4192	-
LSD (0.05)		292	390	225

Greenhouse Research by TVA at Muscle Shoals

Research Directly Related to TVA-AID Project

Yield Response of Flooded Rice to Added P as Affected by P Source, Soil pH, and Preflood Incubation--F. E. Khasawneh, O. P. Engelstad, Jane Copeland, and Greenhouse Staff. Response of flooded rice to P from a North Carolina phosphate rock (PR) was equal to P response from concentrated superphosphate (CSP) when preflood soil pH was 4.5; it was inferior when preflood soil pH was 6.5. The difference in rice response to PR could not be attributed to a lowering of soil pH in the rhizocylinder of rice roots, nor to initial reaction between the acid soil and PR prior to the onset of anaerobic conditions. An alternate hypothesis is suggested to account for dependence of PR effectiveness on preflood soil pH: that PR dissolution is a function of the ability of the soil to provide a sink for Ca^{++} and $HPO_4^{=}/H_2PO_4^{-}$ ions.

Response of Rice to Granular Phosphates of Low Solubility: Effects of Post-Flood Stirring--O. P. Engelstad and Greenhouse Staff. An experiment was conducted with flooded rice to determine the effect of stirring the flooded soil on the agronomic performance of granular phosphate rocks (PR). Two pilot plant products were tested: urea-PR (18-18-0) and partially acidulated PR made from North Carolina PR. Each was compared with fine and granular (using pressure) forms of the latter as well as with granular CSP.

Stirring the soil resulted in apparent increases in yield for all treatments, including the check. However, only the stirring effects for urea-PR, PR (-6+9), and PR (-100) were statistically significant. Overall, the sources decreased in effectiveness as follows: CSP > fine PR > partially acidulated PR (granular) > urea-PR (granular) > granular PR.

Effect of N Source and Water Management on Response of Rice to Zn--P. M. Giordano, J. J. Mortvedt, O. P. Engelstad, and Greenhouse Staff. Several rates of $CO(NH_2)_2$ and $(NH_4)_2SO_4$ with or without ZnO were applied to flooded and nonflooded Crowley sil (limed to pH 7.5) to determine response of Bluebelle rice to Zn. Yields with both N sources were greater on flooded than on nonflooded soil. In the absence of applied Zn, total dry matter production with $CO(NH_2)_2$ was slightly lower than with $(NH_4)_2SO_4$ on flooded soil and considerably lower on nonflooded soil. Concentration of Zn was higher in straw and grain of plants grown on flooded than on nonflooded soil. Although concentration of P was unaffected by N source or Zn rate, there was some indication that translocation of P from straw to grain may be depressed in nonflooded rice. Concentration of N was lower in straw grown on flooded than on nonflooded soil due to apparent dilution. Whereas both N sources resulted in similar N concentrations in straw at all rates of N application, the N concentration in grain increased with N rate.

Response of Corn to Chlorospodiosite and Related P Sources--S. E. Allen and Greenhouse Staff. A greenhouse pot experiment was conducted with corn grown on Mountview silt loam to compare the effectiveness of chlorospodiosite (Chlor-1) with concentrated superphosphate (CSP), Thomas slag, and North Carolina phosphate rock (NC-PR). Oil-prilled urea--phosphate rock (UPR), $FeAlNH_4P_2O_7$, and monomethyl phosphate were included in the experiment. Based on yield of forage and uptake of P by two crops, each of 6-weeks' duration, the following conclusions were drawn:

1. Chlor-1 was slightly less effective than CSP, Thomas slag, or NC-PR, from which Chlor-1 was prepared.

2. Granular UPR was a poor source of P; its effectiveness was greatly increased by reducing the particle size to -35 mesh.
3. $FeAlNH_4P_2O_7$ was unavailable to the crop.
4. Monomethyl phosphate was equivalent to or slightly more effective than CSP.

Research Indirectly Related to TVA-AID Project

Response of Several Rice Varieties to Zn in Moist or Flooded Soil--P. M. Giordano, J. J. Mortvedt, and Greenhouse. Several varieties of rice from Mexico and the Dominican Republic currently under investigation in Puerto Rico for adaptation to upland culture were compared with some established United States varieties with regard to Zn response on moist and flooded Crowley sil (pH 7.5). Chontalpa (Mexico), Bluebelle (Texas), and Starbonnet (Arkansas) were most responsive to applied Zn, Juma (Dominican Republic) intermediate, and Sinaloa (Mexico) and Calrose (California) were the least responsive. The Sinaloa varieties (Mexico) appeared to be best adapted to non-flooded conditions whereas Chontalpa and Calrose were poorest. Concentrations of Zn generally were higher in plants grown on flooded than moist soil.

Pattern of Growth and Zinc Accumulation by Rice--P. M. Giordano, J. J. Mortvedt and Greenhouse Staff. Rice plants were harvested at weekly intervals from shortly after emergence through maturity. The objective was to determine the rate of growth and Zn uptake by a Zn responsive variety (Bluebelle) and a less Zn-responsive variety (Calrose) in the presence or absence of Zn applied to Crowley sil (pH 7.5). Dry matter production of Calrose was linear with time of growth and of a similar magnitude until heading, with or without applied Zn. Bluebelle followed a similar pattern where Zn was applied. However, in the absence of applied Zn foliage yield was reduced markedly.

Uptake of Zn was similar for both varieties when Zn was applied. Dry matter production and Zn uptake by the two varieties also were comparable when Zn was applied. However, yield of Calrose was much higher than that of Bluebelle in the absence of applied Zn while Zn uptake was only slightly higher. This suggests that the lesser responsiveness of Calrose to Zn may be due to more efficient utilization of Zn. There was no indication of a greater demand for Zn during reproduction in either variety as was suggested in earlier greenhouse experiments.

Response of Upland Rice to P and Zn--P. M. Giordano, J. J. Mortvedt and Greenhouse Staff. Several rates of P and Zn were applied to Crowley sil (limed to pH 7.5) in factorial combination to determine whether differences in rice growth under flooded and nonflooded soil conditions are related to plant nutrition. Although straw yields were slightly higher in nonflooded rice receiving adequate P and Zn, grain yields were higher in the flooded crop; increased rates of P and/or Zn did not result in equal yields. Except in the highest Zn rate (75 mg) concentrations of Zn in both straw and grain were higher with flooding. Concentration of P increased with rate of applied P and was higher in the grain or flooded than upland rice at a comparable P rate. In contrast, concentrations of N were lower with flooding due in part to dilution from increased growth.

Rice Response to N and P in Flooded and Unflooded Cultures--G. L. Terman, S. E. Allen, and Greenhouse-Analytical Staff. Rates of N from 250 to 2000 mt/pot and P from 0 to 1000 mt/pot were applied for Nato rice grown on Mountview sil and Sango sicl (6.25 kg of soil per pot). Market yield response to N and P was obtained. Yields of straw,

total yields, N uptake, and N recovery were higher on unflooded than on flooded soil cultures. Grain yields, however, were slightly higher with flooding. These results indicate that with adequate applied nutrients, especially of N, rice yields without flooding can approach or even equal those under flooding.

Uptake of N, P, Ca, Mg, and Zn increased with yield response to N and P, while K uptake decreased on the Mountview soil. Concentrations of N and P increased with applied N and P, respectively, while concentrations of other nutrients were diluted in most situations with yield response to N or P.

Results from this experiment show that amounts of N applied in previous pot experiments for rice have been much too low, especially if the crop was grown to maturity.

Response of Corn to S and N in SCU, UAS, and Urea-S--S. E. Allen and Greenhouse Staff. Three greenhouse pot experiments were conducted to measure response to S and N in sulfur coated urea (SCU), urea ammonium sulfate (UAS), and urea-S, as well as estimate N losses from surface applied N sources.

In Experiment 260 less than 20% of the S mixed with the soil was recovered from SCU or urea-S granules by two crops of corn, as compared to 45 or 80% from flowers of S or Na_2SO_4. Crop response followed a similar pattern.

In Experiment 260-A, N sources were surface applied and allowed to dry for two weeks before incorporation into the soil and planting. Recovery of N by two crops of corn was 77-82% for AN as compared to 37-70% for urea, UAS, urea-S, and SCU. Thus, in this experiment, loss of N from urea did not appear to be reduced by light S-coatings or by incorporating S or AS in the granules.

In Experiment 260-B which was similar to 260-A, except for higher greenhouse temperatures, crop response, and recovery of N were not consistently related to source of N. In contrast, N volatilization loss in uncropped cultures as measured by solvent extraction, approached 50% for urea as compared to 20% for urea phosphate.

Response of Rice to Late-Applied N, as Affected by Early N Deficiency--G. L. Terman, S. E. Allen, and Greenhouse Staff. Nato rice grown on Sango sicl (5 kg/pot) under flooding was fertilized with 0.5 g of N/pot mixed with the soil as urea, Ca, $Mg(NO_3)_2$, AN, and AS. Urea was also included at rates of 0.25, 1.0, and 1.5 g of N/pot. These treatments were followed by topdressings of N as AN or urea at 4, 6, 8, and 10 weeks totaling up to 3.5 g/pot.

A soil application of 1.0 g/pot resulted in the maximum yield at 4 weeks. Yields and percent protein of mature grain increased rectilinearly with N applications. Essentially all of the NO_3-N mixed with the soil was denitrified after flooding. Grain and straw yields were highly correlated with tillering and with numbers of grain-bearing stems.

The results indicate that 0.5 to 1.0 g of N/pot as urea or NH_4-N should be mixed with the soil to stimulate tillering, with additional N topdressed later to increase grain yields and protein content.

APPENDIX

DIVISION S-8—FERTILIZER TECHNOLOGY AND USE

Performance of Sulfur-Coated Urea Under Intermittently Flooded Rice Culture in Peru[1]

P. A. Sanchez, A. Gavidia O., G. E. Ramirez, R. Vergara, and F. Mongrillo[2]

ABSTRACT

Short-statured, high yielding rice (*Oryza sativa* L.) varieties grown extensively in northern Peru require extremely high rates of conventional N sources to achieve maximum yields. The recovery of applied N is extremely low due to the use of intermittent flooding. This water management system results in heavy N losses even with properly timed split applications. In search of simpler and more efficient methods of N management, eight field experiments were conducted in the region to evaluate sulfur-coated urea (SCU), an experimental, slow-release N source supplied by the Tennessee Valley Authority. Rice yields were increased an average of 59% more by preplanting-incorporated SCU than by urea or ammonium sulfate applied in the same manner. SCU produced an average of 20% higher grain yield response than topdressed applications of urea or ammonium sulfate. SCU applications increased panicle production, N uptake at harvest, and the apparent recovery of added N. Beneficial effects of SCU were more pronounced in sites where check yields were low, especially less than about 4.8 ton/ha. In sites with high N supplying capacity, SCU produced excessive vegetative growth which resulted in yield reductions at high N rates.

Regardless of an assumed 40% higher unit N cost in SCU, the overall benefits of preplanting-incorporated applications of SCU were favorable since there was a decrease of 40% in the optimum rate of N and the need for precise timing of application was eliminated.

Additional Index Words: slow-release fertilizer sources, nitrogen fertilizer efficiency.

In most rice growing areas of the tropics, intermittent flooding is the predominant form of water management (8). Constant flooding during the growing season is difficult to maintain in many areas because of the variability in rainfall distribution or the limitations in existing irrigation systems. Large losses of added nitrogen take place under alternate flooding and drying due to leaching and denitrification of recently oxidized nitrate ions (4). Low recovery of added N is one of the main factors limiting profitable rice (*Oryza Sativa* L.) production in Peru, where high yielding, short-statured varieties are extensively grown under intermittent flooding. With these varieties, optimum grain yields of 6 to 12 tons/ha are obtained with N applications rates of 200 to 400 kg N/ha (6).

Previous work has shown that single applications of urea or ammonium sulfate incorporated in the topsoil prior to transplanting are very inefficient when compared to split applications topdressed at tillering and panicle initiation (6, 8). The latter practice results in an apparent N recovery of 20 to 30%, which is still quite low when compared to the 40 to 50% recovery commonly attained with constant flooding (1, 9). Previous work showing no significant difference between urea and ammonium sulfate as N sources is considered evidence of the absence of either deficiency or response to S by rice grown in the Coast of Peru (2, 6).

In our search for simpler and more efficient N management practices, arrangements were made with the Tennessee Valley Authority to test the effectiveness of sulfur-coated urea (SCU), an experimental slow-release N source. The purpose of this study was to determine whether SCU applications are more efficient than applications of conventional N sources in intermittently flooded rice culture.

EXPERIMENTAL PROCEDURE

Eight field experiments were conducted in the Lambayeque, Jequetepeque, and Zana Valleys of northern Peru from 1969 to 1972. The climatic characteristics of these and other areas have been described elsewhere (7). The soils are derived from calcareous alluvium and are relatively uniform morphologically. In the eight experiments, topsoil texture ranged from clay loam to clay, pH from 7.9 to 8.3, and organic matter from 1.6 to 2.0%. The dominant clay mineral is montmorillonite. No responses to nutrients other than N have been recorded for rice in these areas (2, 6).

All experiments had a split-plot design with three or four replications. The main plots consisted of N rates varying from 0 to 400 kg N/ha at 80 kg increments, except in Exp. 3 and 6 as indicated in Fig. 1. The subplots consisted of the following source-time combinations:

1. SCU-b: Sulfur-coated urea with dissolution rates of 0.6 to 2.2% N per day; 33 to 37% N, and 10 to 21% S (1). SCU was incorporated into the topsoil immediately before transplanting, hereinafter referred to as the basal application.
2. Urea-b: Commercial urea (46% N), applied as in treatment 1.
3. Urea-t: Commercial urea (46% N), topdressed application half at tillering and half at panicle initiation, broadcast on a thin layer of standing water.
4. AS-b: Commercial ammonium sulfate (21% N, 24% S), applied as in treatment 1. (Only in Exp. 2, 5, and 7.)
5. AS-t: Commercial ammonium sulfate (21% N, 24% S) topdressed application like in treatment 3. (Only in Exp. 2 and 7.)

The following short-statured, high yielding rice varieties were used: 'IR8' in Exp. 1, 'IR8' in Exp. 2, 3, 4, 6, 8, and 'Neptuno' ('IR930-2-6') in 5 and 9. These varieties are very similar in

[1] Paper no. 3937 of the Journal Series of North Carolina State Univ. Agr. Exp. Sta., Raleigh in cooperation with the Ministry of Agriculture and the Universidad Nacional Pedro Ruiz Gallo, Lambayeque, Peru. Presented before Div. S-8, Soil Sci. Soc. of Amer., November 1, 1972 at Miami, Fla. The authors are grateful to the Tennessee Valley Authority for supplying the experimental materials through a contract with the U.S. Agency for International Development. Received Jan. 19, 1973. Approved April 6, 1973.

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DISCUSSION

Direct application of these results to field situations is, of course, unwarranted. The concept that the optimum N/P ratio for a soil increases as more N is supplied should, however, apply equally well to greenhouse and field conditions, provided that the plants are fully utilizing the nutrients available to them and that the supply of neither nutrient reaches toxic levels.

In general, a wide ratio of N to P—on the order of 2 to 1—appears necessary to optimize growth of slash pine, particularly at high N levels. To be effective, both nutrients must be applied simultaneously. Nitrogen enhanced recovery of total soil P by about 3% for each 84 kg/ha (0.25 g/pot) applied.

This greenhouse study suggests limits on amounts of P that can be expected to produce useful responses in field tests. Applications in excess of 200 kg/ha (0.5 g/pot) appear to be antagonistic on the soils studied.

Effectiveness of applied N appears more elusive than that of P. Problems involve a diminishing response at the fairly low level of 250 kg/ha (0.75 g/pot) and a probable tendency of soil microorganisms to compete with the plants. This aspect of tree nutrition clearly deserves further study.

Requirements for Ca and Mg appear closely related to rate of tree growth. Levels of these and other essential elements must be considered when N and P fertilization is prescribed.

These remarks should be applicable not only to Caddo series but a broad range of heavy and imperfectly drained soils.

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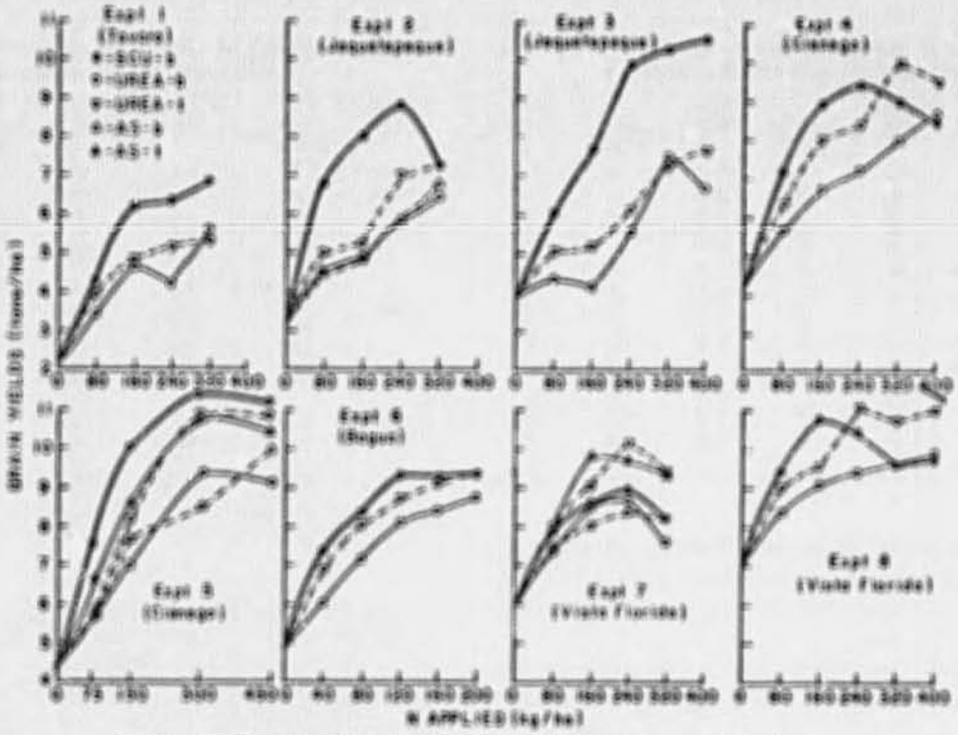

Fig. 1—Yield response by rice of different N source-time combinations.

Table 1—Grain yield response to various source-time combinations by individual experiments (mean of N rates)

Exp. no.	Yield with no applied N	Yield response					LSD 5.0%
	ton/ha						
1	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—

their yield and nitrogen response pattern and differ mainly in disease resistance and grain quality. Rice seedlings were grown from 25 to 65 days in ordinary seedbeds and were transplanted in 15 m^2 subplots in hills spaced at 25 by 25 cm. The experiments were flood-irrigated whenever water was available. Intervals between floodings ranged from 8 to 12 days. Weeds were satisfactorily controlled and no significant pest or disease attacks were observed. Plant height, tillering, dry matter production, and N uptake were determined at 30 days after transplanting, at panicle initiation, at 50% flowering, and at harvest. Grain yields were determined in a 5 m^2 central area devoid of border effects and adjusted to 14% moisture. Yield components were determined in one hill randomly chosen at harvest. Apparent N recovery was calculated by the uptake differences from the check plots located in each main plot. Regression equations for each source-time combination were used to calculate the optimum economic yield and N rate, based on the first derivative and the 1972 cost-price ratios.

RESULTS AND DISCUSSION

Yield Responses

The main effects of the source and time treatments are shown in Table 1 in which the experiments are arranged in order of increasing grain yields without added N. No significant differences were observed between urea and ammonium sulfate sources in the experiments where this comparison was made. Topdressed applications of urea or ammonium sulfate were significantly superior to basal applications of these sources in all but one experiment. These results confirm previous observations about the similar performance of these carriers and the superiority of properly timed topdressed applications over a basal dose.

SCU-b produced a significantly higher yield response than basal applications of urea or ammonium sulfate in all but one experiment in which the difference was not large enough to be significant. The average yield response of SCU-b was 4.06 ton/ha or 59% higher than the average yield response of basal urea applications (2.55 ton/ha).

SCU-b was significantly superior to topdressed applications of the conventional sources in four experiments, not significantly different in three, and significantly inferior in one (Table 1). As the check plot yields increased, the superiority of SCU-b over the topdressed conventional sources declined. The overall yield response of SCU was 20% higher than that of the topdressed urea (3.37 ton/ha).

The interaction between N source-time combinations and N rates was significant in all cases. Yield response curves are shown in Fig. 1. In all experiments, SCU-b outyielded at all N levels basal applications of urea or ammonium sulfate. SCU produced a clearly superior response in Exp. 1 to 4 in which the yields without added N were lower and where the alternate wetting and drying cycles were more pronounced. In Exp. 4, 5, 6, and 8, SCU-b produced a more marked yield response than topdressed applications of urea or ammonium sulfate. Although the maximum yields obtained with each source did not vary significantly in these experiments, the crops required a lower N

Table 2—Effects of source-time combinations on plant characteristics and nitrogen relations in Exp. 1

Source and time	Rate	Grain/straw ratio	Panicles	N at harvest	N uptake	Recovery of added N
	kg N/ha		per m²	%	kg N/ha	%
Check	0	1.12	199	0.78	31	--
SCU-b	80	1.21	257	0.68	48	48
	160	1.34	303	0.81	91	36
	240	1.47	396	1.01	152	50
	320	1.41	407	1.18	230	50
	Mean	1.37	351	1.00	97	36
Urea-t	80	0.95	247	0.75	53	28
	160	1.11	295	0.81	72	30
	240	1.41	351	0.79	87	31
	320	1.49	398	0.86	77	34
	Mean	1.29	370	0.80	65	30
Urea-b	80	1.34	328	0.80	55	31
	160	1.42	343	0.75	61	19
	240	1.71	351	1.05	86	28
	320	1.61	398	1.02	83	17
	Mean	1.57	338	0.91	71	22

rate as SCU to attain maximum yields. In Exp. 7, topdressed applications of urea and ammonium sulfate produced significantly higher maximum yields than basal SCU at about the same N rate.

Additional data (not shown) indicate that a single topdressed SCU application at the tillering stage was as effective as SCU-b.

Besides the lower N rates required with SCU-b, an additional practical advantage of this source is the elimination of the precise timing necessary when conventional N sources are topdressed at the panicle initiation stage.

Plant Characteristics

In order to explore further the nature of the response differences in sites with low and high yield levels without added N, several crop parameters were determined and the results for Exp. 1 and 8 are shown in Tables 2 and 3, respectively. In terms of grain yields, SCU was overwhelmingly superior to the conventional sources at all N rates in Exp. 1, while SCU approached the maximum yield at a lower N rate than topdressed urea in Exp. 8.

The grain/straw ratio of the dry matter at harvest is a good indicator of the effectiveness of N use for grain production. In Exp. 1, grain/straw ratios increased with increasing N rates with little difference between sources, indicating severe N deficiency and more marked responses. In Exp. 8 grain/straw ratios decreased with increasing N rates, suggesting a high initial N supply in the soil. The sharp decrease in grain/straw ratios at high SCU rates reflects the negative yield response observed and indicates excessive vegetative growth caused by too much available N.

The number of panicles per unit area is the yield component most closely correlated with yield responses in short-statured rice varieties (8). In both experiments, SCU applications produced more panicles per m² than conventional urea, suggesting that the slow-release source encourages the production and maintenance of more tillers than the completely soluble sources. Extremely high panicle production levels are usually accompanied by decreases in filled grains per panicle and grain yields in transplanted rice (3). This may also account for the yield decreases obtained with 320 and 400 kg N/ha as SCU in Exp. 8. (Fig. 1). Possibly the same conditions are reflected in Exp. 2, 4, and 7.

Table 3—Effects of source-time combinations on plant characteristics and nitrogen relations in Exp. 8

Source and time	N rate	Grain/straw ratio	Panicles	N at harvest	N uptake	Recovery of added N
	kg N/ha		per m²	%	kg N/ha	%
Check	0	1.68	266	0.88	108	--
SCU-b	80	1.65	327	0.91	151	54
	160	1.64	383	0.97	175	43
	240	1.41	418	1.10	192	35
	320	1.13	440	1.04	223	34
	400	1.02	454	1.20	228	30
	Mean	1.29	414	1.05	195	39
Urea-t	80	1.38	264	0.96	137	24
	160	1.61	333	0.93	167	34
	240	1.55	411	1.07	199	34
	320	1.46	434	1.11	226	31
	400	1.32	439	1.10	232	26
	Mean	1.38	371	1.03	176	28
Urea-b	80	1.44	298	0.91	137	36
	160	1.61	385	0.96	165	22
	240	1.37	344	0.91	179	30
	320	1.13	434	0.96	179	22
	400	1.18	451	1.09	198	22
	Mean	1.29	362	0.97	167	26

Table 4—Optimum N application rates and grain yields of source-time combinations calculated from yield regression equations

Exp. no.	N rate					Optimum grain yields				
	SCU-b	Urea-b	Urea-t	Ab-b	Ab-t	SCU-b	Urea-b	Urea-t	Ab-b	Ab-t
	kg N/ha					t/ha				
1	256	348	480	--	--	6.72	5.31	5.58	--	--
2	351	426	469	417	--	8.62	7.10	8.10	6.06	--
3	372	*	*	--	--	10.68	*	*	--	--
4	256	521	522	--	--	8.80	9.21	11.16	--	--
5	290	374	348	478	334	11.74	9.35	11.05	10.06	10.92
6	167	306	174	--	--	5.50	6.77	5.82	--	--
7	188	189	234	216	217	6.16	8.40	5.42	6.45	8.90
8	222	301	303	--	--	10.78	10.57	11.09	--	--
8 Sa	224	323	369	--	--	8.47	8.41	8.38	--	--
	Prices:	Rough rice: $0.11/kg Urea: $0.35/kg N					Ammonium sulfate: $0.28/kg N Sulfur-coated urea: $0.34/kg N			

* No quadratic term.

Nitrogen Parameters

Tables 2 and 3 show that the soil supplied up to 31 kg N/ha to the rice crop in Exp. 1 and as much as 108 kg N/ha in Exp. 8. The N content of the above-ground plant parts and the N uptake at harvest were higher with SCU applications in both experiments. At high rates of SCU in Exp. 8, the total N uptake was substantially above the level considered optimum for the site and variety, 180 kg N/ha, according to data from a concurrent study.

The apparent recovery of added N, calculated by uptake differences show that SCU was a more efficient source in both experiments, with an average recovery range of 36 to 39% and maximum recovery values of 48 to 54%. Commercial urea averaged from 20 to 38% recovery with highest values of 31 and 30% (Tables 2 and 3). Although the recovery values at harvest are similar for basal and split applications of commercial urea, the superior behavior of split applications is related to a higher percent N contents in the plants at the critical stages of tillering and panicle initiation. Basal applications of urea tended to have a lower percent N content at panicle initiation.

Economic Interpretation

The optimum rate for each source-time combination appears in Table 4 along with the economically optimum grain yield levels. These calculations are based on 1972

prices of rough rice, urea, and ammonium sulfate in Peru and the assumption that the unit cost of SCU is 48% higher than commercial urea, as suggested by TVA personnel. (More recent (December, 1972) TVA estimates based on larger scale production suggests that the unit cost of SCU is 32% higher than commercial urea.) Quadratic regression equations accounted for 65 to 95% of the variation in yields as indicated by the R^2 values obtained. Optimum rate calculations were not possible for two treatments in Exp. 3, as only the linear term in the equation was significant. SCU-b produced average optimum yields almost identical to those of topdressed urea, but the optimum N rate required to reach the optimum yield was about 40% less with SCU-b than with topdressed urea (224 vs. 369 kg N/ha). In many experiments the difference was substantially wider. Even in the sites with high yields without added N, the N rate required to reach the optimum economic yields was substantially lower with SCU-b.

CONCLUSIONS

This study shows that basal applications of sulfur-coated urea are more efficient than basal or topdressed applications of urea or ammonium sulfate in intermittently flooded rice culture in northern Peru. The lack of differences between urea and ammonium sulfate and the superiority of SCU over these sources as basal applications indicate that the beneficial effect of SCU is related to its slow-release properties in an environment conducive to high losses of applied N. Plant growth and N parameters indicate that SCU is indeed more efficient in supplying N to the rice plant and that N uptake could become excessive and even reduce yields at high rates of SCU applications.

These results have been obtained with high yielding, lodging-resistant varieties, and cannot be directly extrapolated to tall, traditional rice varieties, or to conditions of constant flooding.

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DIVISION S-9—SOIL MINERALOGY

Amorphous Coatings on Mineral Surfaces[1]

R. C. JONES AND G. UEHARA[2]

ABSTRACT

Amorphous coatings on mineral surfaces too thin to be resolved by most electron microscopes were detected bridging particles suspended over holes in the supporting substrates. The coatings are gel-like in appearance, may flow when wet, shrink and become porous when heated, cement primary particles into large masses, and exhibit a coat-of-paint effect with curved solid-air interfaces. Amorphous gel coatings were found in alumino-silicate systems, in high aluminum soils, and on quartz surfaces.

Additional Index Words: gel-halls, alumino-silicate system, aluminum system, silica system, electron microscopy, holey substrates.

WHILE THE ROLE played by amorphous materials in influencing soil behavior remains speculative, enough has been learned in the past few years to warrant reexamination of the topic. This paper presents new information which shows how amorphous materials are distributed in the clay fraction of soils. The evidence is illustrated through a series of high resolution electron micrographs.

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recovery of oxides of nitrogen from this kind of system is desired. However, the quantities of oxides of nitrogen measured in the alkaline permanganate solution (trap) are related to the quantities of oxides of nitrogen volatilized and thus, in this report, these two terms are used interchangeably. The quantities of oxides of nitrogen given off from raw humus sods decreased in the order of treatment with $Al(NO_3)_3 > Ca(NO_3)_2 > NH_4NO_3 > KNO_3$.

The quantities of nitrogen oxides volatilized in 7 days in the feather moss samples treated with KNO_3, NH_4NO_3, $Ca(NO_3)_2$, and $Al(NO_3)_3$ corresponded to 9, 15, 18 and 53 g N ha^{-1}, respectively. These values are less than half those observed for agricultural soils (Getmanets, 1972).

When treated with nitrates, the raw humus sods covered with sphagnum mosses volatilized less oxides of nitrogen than those with feather mosses. Six, 9, and 18 g N ha^{-1} of oxides of nitrogen were volatilized in the sphagnum-covered raw humus materials treated with NH_4NO_3, $Ca(NO_3)_2$, and $Al(NO_3)_3$, respectively.

The experimental results showed that the proportion of added nitrate given off as oxides of nitrogen is small. Since the presence of highly poisonous gaseous oxides of nitrogen could be detected (by smell) in the nitrate-treated field plots, however, the significance of the volatilization of oxides of nitrogen needs to be understood.

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DIVISION S-8—FERTILIZER TECHNOLOGY AND USE

Response by Flooded Rice to Phosphate Rocks Varying in Citrate Solubility[1]

O. P. ENGELSTAD, AROON JUGSUJINDA, AND S. K. DE DATTA[2]

ABSTRACT

Studies were conducted in the greenhouse and in the field to evaluate several phosphate rocks for flooded rice (*Oryza sativa* L.). A close relationship was found to exist between first-crop yield response to applied P and citrate solubility in a series of phosphate rocks representing the theoretical range in this parameter. Greenhouse (TVA) and field data (Thailand) showed quite similar results in this respect.

The same general pattern of effectiveness among sources persisted through the second crop as found for the first crop. The residual effectiveness of triple superphosphate (TSP) remained higher than that of the phosphate rocks; however, the relationship between initial citrate solubility of the phosphate rocks and relative effectiveness in the second crop was rather poor.

A procedure is presented which enables one to make the choice of P source on the basis of both agronomic effectiveness and prices of P in TSP vs. phosphate rock.

Additional Index Words: rock phosphates, triple superphosphate, Thailand, acid sulfate soil

IN THOSE AREAS of Southeast Asia where rice (*Oryza sativa* L.) is grown on acid soils, phosphate rocks have often been applied directly as sources of P for rice. These sources are lower in price than acidulated phosphates and can represent a means of reducing fertilizer cost where transport costs are not too great.

It has often been assumed that all phosphate rocks are composed of fluorapatite and are similar in effectiveness for direct application. However, it has been shown by a number of workers that there are substantial differences in effectiveness among phosphate rocks from different deposits. These differences have been shown by Armiger and Fried (1), Caro and Hill (3), and Lehr and McClellan (7) to be related to their solubility in ammonium citrate or citric acid solution, and that this solubility in turn is related to the degree of substitution of CO_3^{2-} and F^- for PO_4^{3-} in the apatite structure. In fact, Lehr and McClellan have found in an extensive examination of important world deposits that, with few exceptions, the apatites were not fluorapatite, but belonged to a series of carbonate apatites.

Emminger, Pearson, and Armiger (4) found that solubility in sequestrene and citrate solutions was a better measure of availability of phosphate rock than F content or specific surface. They also found that none of the phosphate rocks produced as high yields as superphosphate, regardless of rate added.

Using a series of phosphate rocks varying in citrate solu-

[1] Contribution from Soils and Fertilizer Research Branch, National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, AL 35660. This research was conducted jointly by TVA, the International Rice Research Institute, the Rice Department, Thailand, and was supported in part under an AID Participating Agency Service Agreement No. RA(QA)-5-69. Received 23 Oct. 1973. Approved 8 Feb. 1974.

[2] Agronomists at TVA, Ministry of Agriculture (Thailand), and the International Rice Research Institute, respectively.

Table 1—Sources of phosphate rocks used in these studies and partial chemical and physical analyses*

Deposit	Description		Total P %	Citrate-soluble P (% of total P)	Absolute citrate solubility index	CO_2 content of apatite %	Percent -100 (Tyler mesh)
North Carolina	Colloidal phosphorite	(Sedimentary)	13.1	26.1	19.8	1.0	98
Florida (pebble)	"	(Sedimentary)	14.2	20.6	14.8	1.7	76
Florida (concentrate)	Pebble	(Sedimentary)	14.5	15.2	10.1	1.2	92
Idaho	Hard phosphorite	(Sedimentary)	14.1	11.5	5.5	1.8	98
Tennessee	Brown rock	(Sedimentary)	13.4	16.7	5.1	1.5	78
India (Udaipur)	"	(Metamorphic)	17.5	5.3	1.7	0.7	89
Missouri	"	(Igneous)	14.3	1.4	1.0	0.3	94

* Analytical data from June 1967 Progress Report of Fundamental Research Branch, TVA. The AOAC procedure was used in the determination of citrate-soluble P.
† Determined by chemical analysis.

bility, Terman, Allen, and Engelstad (8) reported a good relationship between AOAC-available P and response by flooded rice in greenhouse pots. Bengtson, Sample, and Allen (2) showed the same relationship with slash pine seedlings.

The purpose of this paper is to present results of both greenhouse and field experiments conducted to evaluate the relationship of citrate solubility of phosphate rocks to agronomic effectiveness for flooded rice.

EXPERIMENTS CONDUCTED AND RESULTS

A series of phosphate rocks was selected to represent a wide range of citrate solubility; this was a different series than used by Terman et al. (8) and Bengtson et al. (2). For convenience in procurement, most of these phosphate rocks were from deposits in the USA. However, a phosphate rock from India was included in the greenhouse experiment.

The chemical characteristics of these phosphate rocks are presented in Table 1. The AOAC citrate-soluble P content (as percentage of total P) varies in this series from 1 to 26%. The absolute citrate solubility (ACS) index as defined by Lehr and McClellan (7) is also provided in Table 1. This index is calculated as follows:

$$ACS = \frac{\text{AOAC citrate-soluble P (\%)}}{\text{Theoretical P (\%) of apatite}}$$

The ACS values are useful when comparing phosphate rocks of varying apatite content. The CO_3 substitution in the apatite structure is indicated by the CO_2 content, which varied between 0.2 and 5.0%. The percentage of each phosphate rock passing through a 100-mesh screen is also shown (varying between 76 and 99%). Further information on these phosphate rocks is provided by Lehr and McClellan.

Greenhouse Experiment

Mountview silt loam, limed to pH 5.2 with a 2:1 mixture of $CaCO_3$–$MgCO_3$, was placed in 25-cm plastic pots in 5-kg lots each. The phosphate rocks listed in Table 1 and triple superphosphate (TSP), both fine and granular, were added at rates of 50, 100, and 200 mg of total P per pot (10, 20, and 40 ppm) and mixed with the soil. Three replicates were prepared of each treatment. Rice (var. 'Nato') was seeded directly and the soil brought to field capacity. After emergence, the plants were thinned to 12 per pot. Flood water was applied at 3 weeks after seeding and maintained continuously at a depth of about 4 cm during the growth period. Other nutrients, such as N, S, and micronutrients, were added in amounts adequate for good growth.

The rice was harvested during the boot stage of growth, dried, weighed, ground, and analyzed for P, using a molybdovanadate procedure.

The soil was allowed to dry, then passed through a 12-mm screen, and returned to the pots. A second crop was then grown under the same procedure as for the first crop, except that no fresh additions of P were made.

The response patterns were essentially identical for yield of dry matter and P uptake. The first crop yield data are plotted in Fig. 1 as a function of rate of P added. Much difference in response was obtained among the phosphate rocks. The most soluble phosphate rock—the North Carolina—approached but did not equal TSP in effectiveness for yield. The least citrate-soluble sources—Missouri and India—were quite ineffective.

Relative agronomic effectiveness (RAE) values were calculated for the two crops. These values (Table 2) indicate on a relative scale the agronomic effectiveness of the various phosphate rocks compared with that of TSP. For the most part, the RAE values were similar for both crops.

The relationship between RAE and citrate solubility for the phosphate rocks is shown graphically in Fig. 2. The

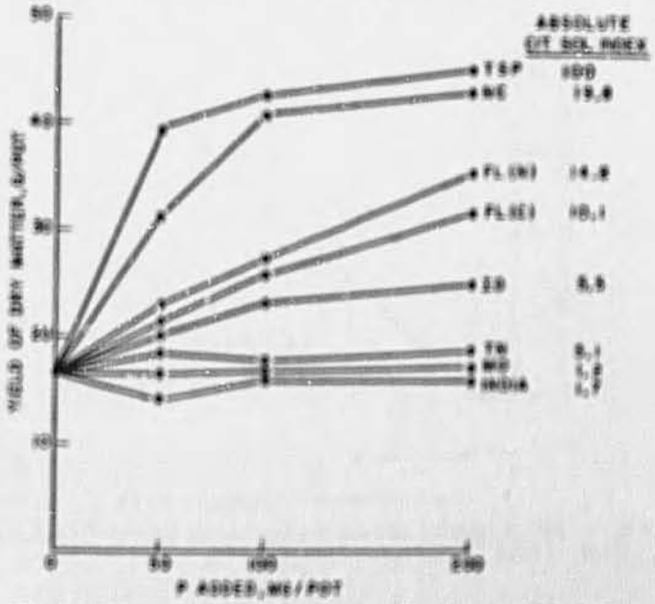

Fig. 1—Effect of various P sources on the forage yield of rice in a greenhouse experiment (TVA).

Table 2—Relative effectiveness of various phosphates over two consecutive crops (greenhouse experiment)*

Source of P	Crop 1	Crop 2
North Carolina	84	87
Florida (pebble)	65	68
Florida (concrete)	37	37
Idaho	34	41
Tennessee	6	10
Idaho (Gidgeye)	0	6
Missouri	0	14
TSP (1:1 mixed)	90	70
TSP (2:1:2 mixed)	100	96

* After averaging the dry matter yields over all rates, these values were calculated with the formula:

$$A = \left(\frac{Y_{\text{exp-control}}}{Y_{\text{TSP-control}}}\right)^2 \times 100.$$

RAE values are plotted against both the ACS index and the citrate-soluble P content. Because of variation in content of apatite among the phosphate rocks, the ACS index was more appropriate than the citrate-soluble P content. The linear regression model accounted for 95% of the variation in relative effectiveness using the ACS index as compared with 90% for the citrate-soluble P content.

Field Experiments

Using the phosphate rocks from the USA listed in Table 1, field experiments were established in 1969 on wet-season rice at two locations near Bangkok, Thailand. This was a cooperative effort (5) involving the Rice Department of the Ministry of Agriculture, the International Rice Research Institute, TVA, USAID, and Kasetsart University.

Klong Luang Rice Experiment Station. The soil was developed from brackish water sediments. It possesses a heavy clay texture throughout the profile with a black upper horizon. This is an acid-sulfate soil, belonging to the Ongkarak series. The pH of the plow layer of the experimental site was about 4.6.

Bangkhen Rice Experiment Station. The Bangkhen soil was derived from alluvial sediments, having a heavy clay texture throughout the profile. At the experimental site, the pH of the plow layer was about 5.8.

A rice variety known as 'RD-1' was used in both experiments; this is a cross between 'Leuang Tawng' and 'IR-8.' 'Leuang Tawng' is a tall Thai variety known for being nonsensitive to photoperiod. A split-plot design was used in these experiments with 4 rates of P (11, 22, 44, and 88 kg of P/ha) applied as main plot treatments and with the sources of P as subplot treatments. There were two check plots in each replicate. The extra check plot was included to permit the application of fresh TSP standard for the succeeding crop; the purpose of this was to permit accurate measurement of the residual effectiveness of the phosphate rock.[3] The P fertilizers were broadcast on the mud and then incorporated in the soil during the last harrowing. At time of transplanting, immediately before the last harrowing, 100 kg/ha of N as ammonium sulfate and 33 kg/ha of K as potassium chloride were applied. A total of 40 kg/ha of N as ammonium sulfate was applied later in two topdressings with about 5-cm depth of water on the plots.

Three to six 21-day-old seedlings per hill were planted 20 by 20 cm apart in straight rows. Hand weeding was used and insecticides were applied for insect control. Grain yield was measured by sampling 5 m² of each plot excluding border rows. The date of heading in each treatment and the yield components at harvest were also recorded.

The average yields of rough (unhulled) rice for both locations are plotted in Fig. 3 for the first crop (1969 wet season). The greatest yield response was obtained at Klong Luang; however, a quite satisfactory yield response was obtained to applied P at Bangkhen as well.

Relative agronomic effectiveness values were calculated for these data and are presented in Table 3. The values for the first crop are plotted against ACS index in Fig. 4 for both locations. The relationship was linear for the Bangkhen location and curvilinear for Klong Luang. The simple linear regression model accounted for 88% of the variation in the RAE values for Bangkhen; a "square root"

[3] The Klong Luang experiment was continued through eight successive croppings to evaluate the long-term residual effects of these phosphate rocks. The Bangkhen experiment was terminated after the third crop. These residual yields will be presented elsewhere.

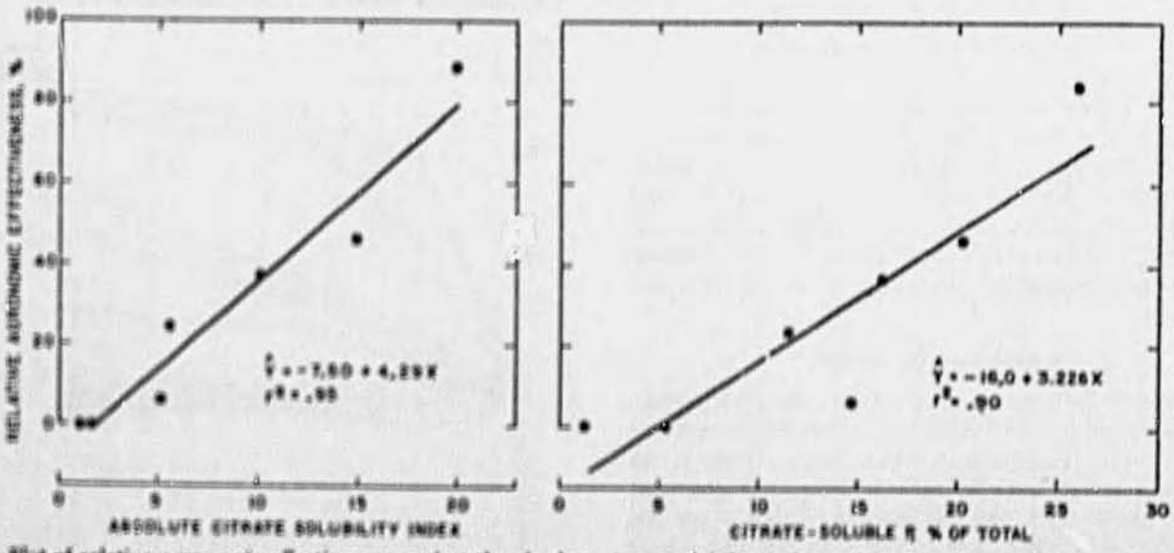

Fig. 3—Plot of relative agronomic effectiveness against the absolute citrate solubility index and against the content of citrate-soluble P, % of total (greenhouse experiment).

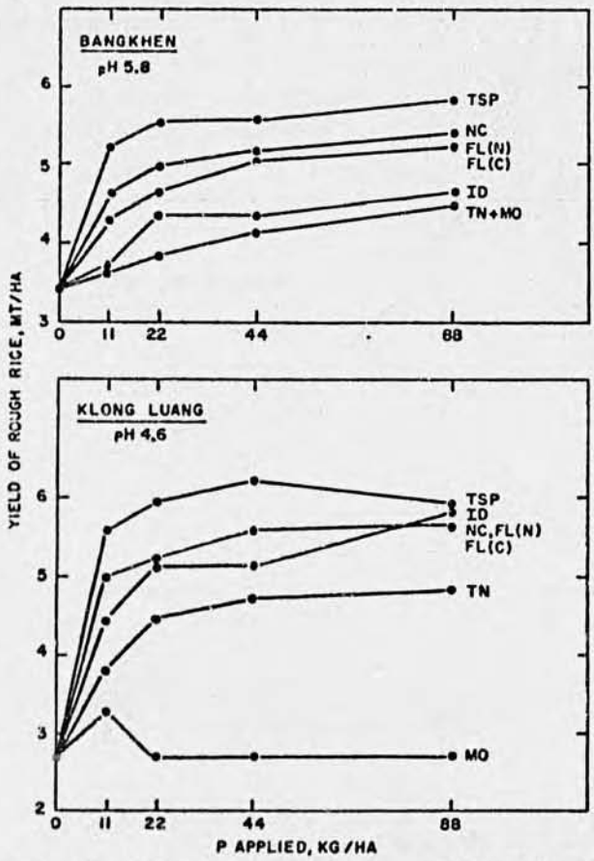

Fig. 3—Yield of rough rice at Klong Luang and Bangkhen Rice Experiment Stations, Thailand, as affected by rate and source of P applied (crop 1).

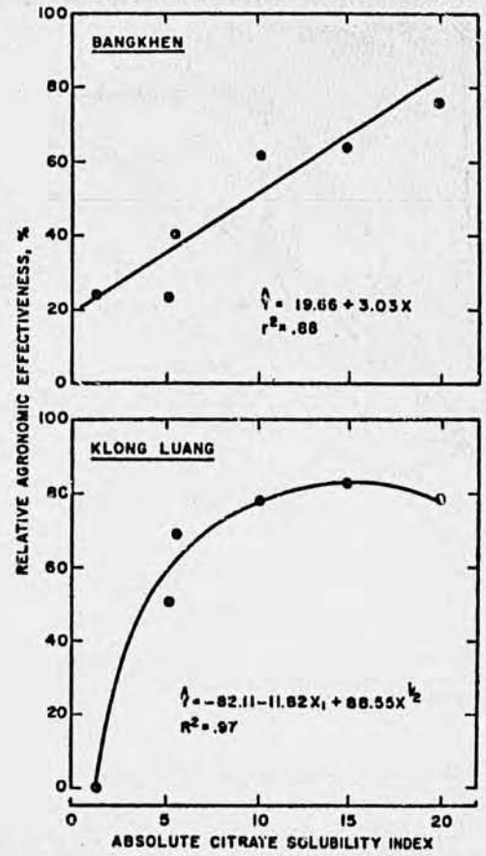

Fig. 4—Relative agronomic effectiveness (%) of P sources plotted against citrate solubility index for both Thailand field experiments (first crop only).

regression model accounted for 97% of the variation in RAE values at the Klong Luang location.

These experiments were continued during the dry season of early 1970 to ascertain the residual effectiveness of the various sources applied to the first crop. No new P was applied except for the fresh TSP standard mentioned above. The experiment otherwise was conducted in a manner similar to that followed in the first crop.

The response to both freshly applied and residual P was marked at the Klong Luang location and marginal at Bangkhen. In fact, at the latter location, the response was so small that little can be said regarding residual effectiveness. The yield data from crop 2 at the Klong Luang experiment are plotted in Fig. 5.

Relative agronomic effectiveness values (Table 3) were calculated for the Klong Luang data using both the residual and freshly applied TSP as standards. It is of interest to note that the superiority of TSP over the phosphate rocks persisted through the second crop. The main difference in the residual effects is that, with the exception of the Missouri rock, the marked relationship between citrate-soluble P content of the phosphate rocks and RAE had largely disappeared. In this acidic soil (pH 4.6), P would by this time be supplied by intermediate reaction products in addition to residues of the initial apatite.

The TSP applied to the first crop declined slightly in effectiveness relative to the freshly applied TSP. This presumably resulted from crop uptake and reaction with the soil to form less soluble products. Such effects may have been more important at the lower rates, since the two TSP curves converged at the highest rate of application.

These data from Klong Luang indicate that (i) residual effects of all rocks except Missouri were substantial; (ii) the relationship between relative agronomic effectiveness of the phosphate rocks and citrate solubility levels was largely obscured; and (iii) the general superiority of TSP over phosphate rock in terms of effectiveness persisted through the second crop.

DISCUSSION

Greenhouse and field data presented in this paper show clearly that there are substantial differences among phos-

Table 3—Relative agronomic effective values for field experiments in Thailand

Source	Klong Luang Crop 1*	Klong Luang Crop 2†	Bangkhen Crop 1*
North Carolina	78	59	76
Florida (north)	83	74	64
Florida (central)	78	69	6
Idaho	69	63	50
Tennessee	51	65	23
Missouri	0	0	24
TSP (crop 1)	100	94	100
TSP (crop 2)	---	100	---

* Calculated after averaging the yield of rough rice for the 11, 22, and 44 kg rates of P.
† Calculated as above except that the average yield increases to 22, 44, and 88 kg rates of P were used.

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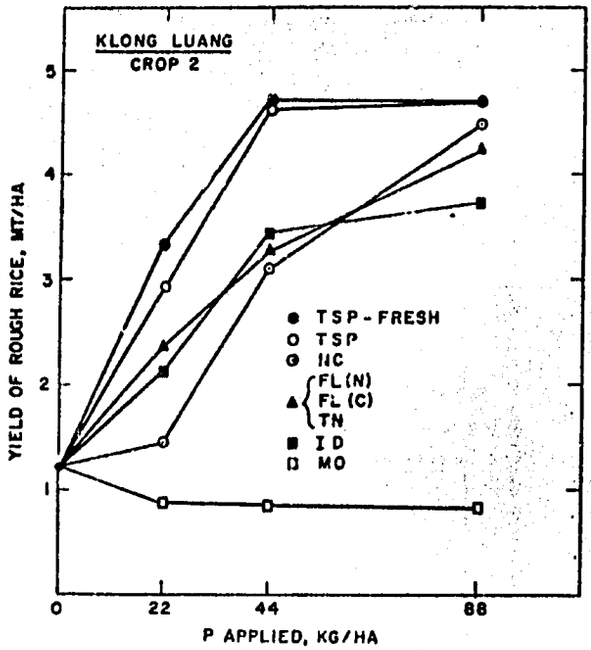

Fig. 5—The residual effectiveness of various P sources for crop 2, as compared with freshly applied TSP. Klong Luang Rice Experiment Station, Thailand.

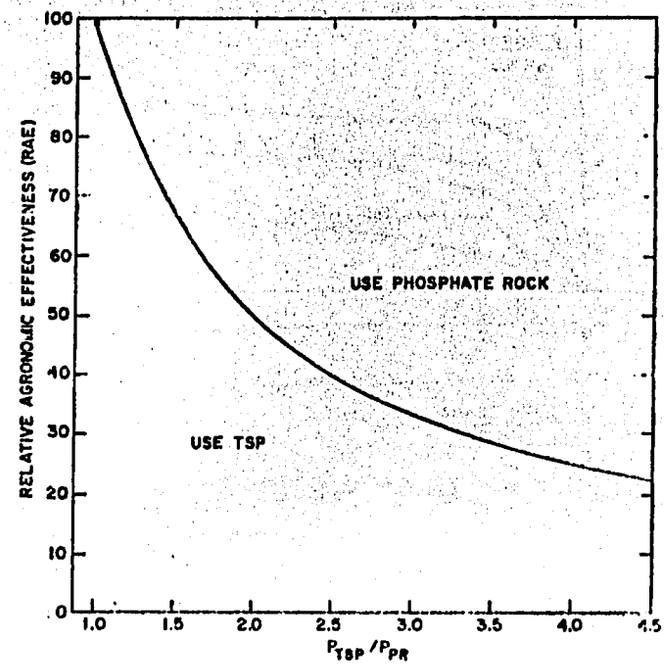

Fig. 6—Relationship between relative effectiveness values (RAE) and the price ratios between TSP and phosphate rock. Such a figure can be used in making a choice between these sources.

phate rocks in terms of agronomic effectiveness for flooded rice. Further, these differences can be predicted by means of citrate solubility or by the ACS index. It appears that the latter is more appropriate where the content of apatite varies among phosphate rocks. The most soluble phosphate rocks approached but did not actually equal TSP in limiting (maximum) yield in these experiments, regardless of rate applied. This agrees with the results of Ensminger, Pearson, and Armiger (4). One needs to consider the definite possibility of some yield loss in choosing a phosphate rock over TSP; such yield losses must be weighed against the lower price of phosphate rock. The explanation for such losses may involve concentration of soluble P in the soil. Khasawneh and Copeland (6) suggest that the growth rate of crop plants is a function of P concentration that can be maintained in the soil solution. If P concentration is limiting or inadequate because of a lower dissolution rate of phosphate rock, the growth rate and ultimate yield will be diminished accordingly.

The RAE values based on yield increases reflect the agronomic effectiveness of these various sources relative to the TSP standard; however, these should be supplemented by an economic analysis before rational choices can be made.

The following calculations will provide an estimate of the relative economic effectiveness (REE).

$$\text{REE} = \frac{Y_{PR}}{Y_{TSP}} \times \frac{P_{TSP}}{P_{PR}} \times 100$$

or

$$\text{REE} = \text{RAE} \times \frac{\text{Price of TSP/kg P}}{\text{Price of PR/kg P}}.$$

If REE exceeds 100 in this calculation, the phosphate rock would be preferable to TSP.

The REE calculations were used in preparing an indifference curve (Fig. 6) wherein RAE values are plotted against P_{TSP}/P_{PR} ratios. The curve itself connects those points at which REE equals 100. When exactly on the curve, it makes no real economic difference what source is chosen. After choosing a suitable price ratio, one can then project upward from that ratio; knowing the RAE value (or estimating it from such data as shown in Fig. 4, using citrate-soluble P content), one can then choose the source on the basis of both agronomic and economic considerations. For example, if the price ratio is 2.5 and the RAE value of the phosphate rock is greater than 40, the rock phosphate in question would be used. However, if the RAE value was less than 40, TSP would be a better choice. There are indications that if the P in the more soluble phosphate rocks (North Carolina, north Florida, central Florida) is less than half as expensive as that in TSP, these rocks would be feasible alternatives to TSP on soils similar to those used in Thailand.

This analysis does not take into account the possibility of lower yields from use of phosphate rock. In addition, only a portion of the various yield response curves was used in this analysis, i.e., up to 22 kg/ha. Beyond this rate, yield response was much less pronounced. It could be argued that at less than maximum yields, TSP would produce a certain yield at lower rates of P than would phosphate rock. This would especially be true for low rates of application. For example, at Klong Luang, 5,500 kg of rice per hectare could have been produced with either 11 kg of P as TSP or 44 kg of P as some of the more reactive phosphate rocks. It should be pointed out, however,

that this is the yield level that would show the widest difference; such is the advantage of hindsight.

Farmers generally prefer granular fertilizers for machine or hand application. This is a disadvantage for the phosphate rocks, which are normally applied in finely divided form. Recently experimental quantities of granular urea-phosphate rock mixtures have been made by TVA. Results of trials with these fertilizers will be reported elsewhere.

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DIVISION S-9—SOIL MINERALOGY

Artificial Weathering of Oxidized Biotite: IV. The Inhibitory Effect of Potassium on Dissolution Rate[1]

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ABSTRACT

Rates of dissolution of oxidized biotites in 0.1*M* 0.01*M* HCl are severely depressed in the presence of 1*M* KCl. The amounts of Al, Mg, Mn dissolved in the first extraction are similar to those found without KCl, however, subsequent extractions remove these elements at 10-20% of the corresponding HCl rates. This effect may be due to a decreased rate of vermiculite formation, thereby reducing the effective basal area exposed to attack. A decrease in dissolution rate with increasing ferric iron content was still apparent in the presence of 1*M* KCl.

Additional Index Words: X-ray diffraction, infrared absorption.

IN EARLIER papers of this series, the role of biotite in soils as a source of both macro and micronutrient elements has been discussed (Gilkes, Young, and Quirk, 1972, 1973a,b). Experiments in artificial weathering using a variety of extractants were undertaken to determine the influence of oxidation of octahedrally coordinated iron on the release of structural cations to solution. The results of this work demonstrated that biotite behaves anomalously with respect to the other common ferromagnesian minerals found in soils. Oxidation leads to the development of a high degree of resistance to cation exchange and dissolution. Several authors have concluded that decreased rates of K replacement in electrolytes shown by oxidized biotites are a result of the inclination of structural hydroxyl adjacent to newly created trivalent iron or vacant octahedral cation sites (Robert and Pedro, 1969; Barshad and Kishk, 1968). Gilkes et al. (1973b) suggested that decreased rates of dissolution of oxidized biotite in 0.001, 0.01, 0.1*M* HCl may also be due to the presence of inclined hydroxyl. In this case a smaller surface area, external and exposed interlayer, may be available for attack if K replacement by hydrogen ions occurs at a slower rate in oxidized biotites. Gastuche (1963) has shown that significant dissolution of the (001*M*) biotite face may occur and it is easily demonstrated that the proportion of exposed (001*M*) face in weathering biotites depends on the percentage K replaced. Rausell-Colom et al. (1965) have shown that hydrogen ions act in an identical fashion to metal cations in K exchange from micas. In particular exchange of K by hydrogen ions will be terminated or greatly reduced by high levels of K in solution. Thus if dissolution of oxidized biotites by acids is carried out at sufficiently high K levels to prevent vermiculization, any differences in dissolution rate that may occur cannot simply be ascribed to differences in rates of K replacement. The following results were obtained from such an experiment which, unlike the experiment described in Parts I and II (Gilkes et al., 1973a,b) does not attempt to simulate natural weathering conditions.

MATERIALS AND METHODS

Further subsamples of the less than 10μ biotites used in K exchange and acid dissolution studies (Gilkes et al., 1973a,b) were used in these experiments. Preparation of sequentially oxidized biotites without intermediate vermiculite formation is

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