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TAILORING OF FERTILIZERS FOR RICE

O. P. Engelstad, et al

National Fertilizer Development Center

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Final report

Prepared for

AGENCY FOR INTERNATIONAL DEVELOPMENT PASA RA(QA)5-69

by

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16. Abstracts

The agronomic activities under this project included basic research and preliminary evaluation of new fertilizers for rice at TVA in Alabama and by field studies in India, Thailand, Ceylon, the Philippines, Peru, Brazil and Columbia. The materials tested included various forms of nitrogen, phosphate and zinc.

TVA results with nitrogen fertilizers showed that yield responses to sulfur coated urea (SCU) were related to dissolution; the release of N from SCU was slower under flooded than under drained conditions, with cyclic rather than continuous flooding, and with larger particle sizes of SCU. In 46 of 56 comparisons in tropical field tests, SCU was superior to urea as a basal nitrogen treatment.

There was a good correlation between the citrate-soluble phosphorous of rock phosphate and the growth response of rice. The effectiveness of rock phosphate as compared to triple superphosphate varied with the source of the rocks; finely ground rock phosphate was a better source of P than granular.

The form of zinc does not seem to be as critical for correcting zinc deficiencies in paddy rice as for upland crops; time and placement of Zn are important and there are marked differences in varietal response.

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Summary

Support for this project, "Tailoring of Fertilizers for Rice," by the Agency for International Development (AID) has contributed greatly to knowledge on rice fertilization. This project has provided stimulus for a multidisciplined approach to improving the efficiency of fertilizers used on rice. It has brought together a group of agronomists and engineers in a balanced approach to meet the project objectives.

Accomplishments of this project are summarized as follows.

AGRONOMIC STUDIES

In this project major emphasis was placed on improving the efficiency of nitrogen fertilizers since losses of this nutrient are known to be serious under delayed or intermittent flooding. Emphasis was also placed on the determination of suitable phosphate sources for rice grown on acid soils. Effort has also been devoted to the correction of micronutrient deficiencies and methods for incorporating these materials with fertilizers.

Nitrogen

Some of the more important findings concerning nitrogen fertilization are:

1. Losses of applied nitrogen are often severe from flooded rice paddies, particularly when flooding is either delayed or intermittent.
2. Among conventional nitrogen sources, ammonium sulfate is often superior to urea for rice grown on acid soils.
3. Nitrification inhibitors have little potential for reducing losses of fertilizer nitrogen from flooded soils.
4. Coated (soluble) nitrogen fertilizers such as sulfur-coated urea (SCU) have a real potential for increasing the effectiveness of applied nitrogen where flooding is delayed or intermittent. As a basal dressing, SCU has shown quite consistent yield increases over uncoated urea under such water management conditions. SCU applied as a basal dressing has also shown some advantage over topdressed urea, although not as consistently. Economic calculations show SCU to compete favorably where there are yield advantages.
5. There are no consistent differences in effectiveness among SCU materials varying in release rate within the range tested (15-25% coating).
6. Large SCU granules release nitrogen more slowly in flooded soil; however, it is expected that coatings can be reduced to the minimum for this material, thereby resulting in economic advantages.

Phosphate

1. There are substantial differences in agronomic effectiveness among rock phosphates of different geographic and geologic origin.
2. There is a good correlation between citrate solubility of the P in rock phosphates and agronomic effectiveness.
3. The rock phosphates of relatively high citrate soluble P content (20-26% of total P) often approach triple superphosphate (TSP) in effectiveness.
4. In relation to agronomic effectiveness of rock phosphates, initial soil pH appears to be as important for flooded rice as for upland crops. The rock phosphates are much more effective on acid soils than they are on alkaline soils; in fact, those tested to date are ineffective on the latter. This importance of soil pH exists in spite of the well-known increase in soil pH that occurs after flooding.
5. As for upland crops, water soluble P is more important for rice grown on alkaline soils than on acid soils.
6. An adequate supply of available P should be present early in the growth period to encourage tillering, yields will otherwise be limited.
7. Relative agronomic effectiveness and price ratios of competing sources can be used jointly making choices; i.e., both agronomic and economic considerations can and should be used in this decision.
8. There are substantial areas of acid soils in the rice-growing regions of Southeast Asia to which rock phosphate can be applied.

Zinc

1. Most of the commonly known zinc sources are satisfactory for flooded rice. There is no advantage for the organic (chelated) carriers of zinc over the inorganic sources.

2. Placement and timeliness of application of zinc are the primary considerations. Rice requires zinc mainly during the early growth stages before expansion of the root system.

3. Marked varietal differences have been found in relation to response to added zinc.

ENGINEERING STUDIES

1. As a concurrent activity, a controlled-release nitrogen product (SCU) has been successfully demonstrated in a 0.9 metric ton/hour (mt/hr) [1 short ton/hour (st/hr)] pilot plant. In addition to controlled release, it has superior physical properties for handling, storage, and transport under high humidity conditions. The product can be blended with unammoniated single or triple superphosphate, whereas uncoated urea cannot. Economics favor this material over other controlled-release nitrogen materials. The potential exists for simplifying the coating, making the product even less expensive for some cropping situations. Current cost estimates indicate that a product can be produced commercially for about 30% more than urea on a nutrient basis.

2. Other compounds such as oxamide were previously identified as having controlled-release properties, but economics based on present technology do not appear favorable.

3. Products including ground rock phosphates, partially acidulated and granulated rock phosphates, and granular urea-phosphate rock have been made and tested as part of this program. The development of relatively simple and inexpensive methods to granulate finely ground rock phosphates provide new opportunities to study agronomic effects of granulation. Tennessee Valley Authority (TVA) has developed a rapid method for estimating the phosphate availability of phosphate rocks that correlates well with chemical composition (carbonate substitution).

4. Some methods for successful incorporation of secondary and micronutrients such as sulfur, iron, zinc, molybdenum, and boron have been demonstrated. Micronutrients have been applied to urea, ammonium sulfate, ammonium orthophosphates and polyphosphates, and single and triple superphosphates. These methods are relatively simple and could be used in less developed countries.

5. The production of experimental and improved materials has provided training for participants from countries such as India, Vietnam, Afghanistan, Indonesia, Kenya, Thailand, Brazil, Colombia, and Mexico.

Introduction

The importance of rice to millions of people in the developing countries cannot be overemphasized. As a major component of the diet, it is considered indispensable to the people of the rice-growing areas. Therefore, numerous research programs have been and are being conducted in many countries to increase production; these studies include the improvement of varieties, the use of more effective plant protection techniques, and more effective use of irrigation water.

To supplement these programs, a TVA-AID study was initiated 4 years ago (July 1, 1968) to increase the effectiveness of fertilizers for rice. Much of the effort in this study was directed toward improving the effectiveness of nitrogen applied to rice grown under conditions of intermittent flooding; over 75% of the rice acreage in Southeast Asia involves this type of water management. Usually this results from a lack of sufficient water or a lack of irrigation facilities to assure a continuous flood. The losses of nitrogen are known to be very serious under discontinuous flooding. Losses occur primarily as a result of nitrification of NH_4-N to NO_3-N during the drained periods. Then, during the next flooding, the NO_3-N is either leached out of the root zone or denitrified to form volatile N_2 or N_2O which escapes to the atmosphere. Leaching losses are apt to occur where water percolates freely downward through the soil; most rice soils, however, have layers that restrict downward movement of water. In the latter case, denitrification losses are more likely.

Various sources of nitrogen were tested under typical water management conditions. Extensive test results are presented on SCU, both from an agronomic and an engineering standpoint. Experimental results with selected ground rock phosphates used for direct application are included. Also tested were various sources and carriers of zinc. Agronomic data were obtained from experiments in the TVA greenhouse, at experiment stations in the United States, and research centers in seven developing countries. Most of the information presented is from the overseas experiments, since the data obtained relate to typical problems of the areas represented.

Background

TVA has considerable experience in developing new fertilizers and making improvements in fertilizer processes. Resources are available at the National Fertilizer Development Center (NFDC) to develop fertilizers from an idea at the fundamental stage to the level of experimental production in relatively small-scale plants. Research agronomists are continuously evaluating these new products from the various stages of production in greenhouse and in field plots. Introductory programs demonstrate the use of these products on farms. Through this integrated program, new fertilizer materials can be produced, evaluated, and accepted or rejected. With the exception of the last step, this approach has been utilized in this project.

The various groups within TVA that participated in this study are listed as follows along with their responsibilities and leaders:

Group	Responsibility	Leader
1. Division of Agricultural Development	Preliminary greenhouse research; coordination of fertilizer evaluation program in field (U.S. and overseas)	O. P. Engelstad

Among the participants in a recent meeting of the Advisory Committee in Bangkok, Thailand are as follows (front row, left to right): Y. Ishizuka, ASPAC, Taiwan; D. S. Mikkelsen, University of California, Davis; W. H. Patrick, Louisiana State University; Sombhot Suwonwaong, Rice Department, Thailand; P. J. Stangel, TVA; O. P. Engelstad, TVA. Back row: S. K. DeDatta, IRRI, The Philippines; J. M.Spain, CIAT, Colombia; Aroon Jugsujinda, Rice Department, Thailand; P. A. Sanchez, North Carolina State University; A. Tanaka, Hokkaido University, Japan.

2. Division of Chemical Development	Production of experimental materials and shipment to research centers	T. P. Hignett
3. International Fertilizer Development Staff	Coordination of agronomic and engineering activities and liaison between TVA and AID	P. J. Stangel

To strengthen the agronomic testing program, a committee of experts on rice fertilization from several countries was formed.[1] This committee defined problems and made recommendations to TVA on fertilizers needed. Experimental materials made through this project were available to the committee members at no cost. In this way, experimental fertilizers were tested on rice in the United States as well as in major tropical areas of the world. Agronomic data from overseas locations given in this report were obtained primarily through this committee This committee functioned without monetary compensation; however, certain members received traveling expenses to attend seminars and meetings to discuss agronomic research results. Cooperation with the committee members and others has been excellent, they felt that this activity offered potential for solving their pressing rice production problems. Experiments in Thailand, The Philippines and Ceylon were coordinated by S. K. De Datta of The International Rice Research Institute (IRRI). By this means, IRRI supplied considerable support to the program. Finally, without the overall support and cooperation extended by AID enabling the experimental materials to be made and tested, this project could not have become a reality.

[1] A list of the names and addresses of these committee members is provided in the Appendix.

Objectives and Scope of Work

The ultimate objective of this project is to complement the momentum gained in rice production by other research programs. The more specific objectives involve the development and testing of new or improved fertilizers for this crop. These are listed as follows:

AGRONOMIC

1. To improve the effectiveness of fertilizer N applied to rice grown under delayed or intermittent flooding; this involves use of fertilizer modifications referred to above.
2. To determine the most suitable sources of P for rice grown on acid soils.
3. To determine suitable sources and carriers of zinc, as well as application methods.

ENGINEERING

1. To develop materials with better physical condition to improve handling and storage properties in the humid tropics.
2. To develop nitrogen materials of reduced dissolution rate in an effort to improve effectiveness.
3. To develop alternative phosphate sources for use on acid soils.
4. To develop zinc materials that offer convenience in application.

The scope of services in this project includes the TVA-NFDC, cooperators in Louisiana, California, India, The Philippines, Thailand, Ceylon, Peru, Brazil, and Colombia. Materials were either produced at the NFDC or purchased for use in the agronomic test program. Slow-release nitrogen materials tested in the greenhouse or overseas program include SCU, oxamide (31.8% N) and isobutylidene diurea (IBDU–31% N); other materials tested were selected ground rock phosphates in finely ground or granulated form, partially acidulated (granulated) rock phosphates, granulated urea-rock phosphates and numerous zinc sources, both organic and inorganic forms. The nature of these products and their processes of manufacture are given under the section headed "Fertilizers Tested."

Agronomic Activities

The agronomic activities conducted under this project can be divided into two main areas. They are: (1) the basic agronomic research and preliminary evaluation of new fertilizers at TVA, and (2) the domestic and overseas evaluation of new fertilizers by the research cooperators (including members of the Advisory Committee). The extension or utilization of this research is indicated by the section "Research Utilization" in the appendix.

AGRONOMIC RESEARCH AT TVA

Since the beginning of this project, 32 greenhouse experiments have been conducted by the staff of the Soils and Fertilizer Research Branch. For the most part, these studies were designed to determine under controlled conditions the fate of nutrients added to the flooded rice system and to evaluate fertilizers for rice. The overall scope of this work is indicated by a list of experiments conducted and summaries for these experiments completed (see Appendix).

Nitrogen

Thus far, the results of the TVA research on N fertilizers can be summarized as follows:

1. Yield responses to SCU were related to dissolution rate as determined in the laboratory. This material performs best for water management systems other than continuous

Technicians harvesting rice from fertilizer experiments conducted in research greenhouse at TVA, Muscle Shoals, Alabama.

flooding—that is, for delays in flooding and/or for cyclical flooding-draining sequences. Under such conditions, nitrification occurs during the unflooded phase leading directly to serious atmospheric losses of N via denitrification upon flooding. (This point will be mentioned again under field results.) The sulfur coat shows promise as a protective device for preventing dissolution and nitrification during the unflooded periods. However, there is little need for such protective devices for systems which are continuously flooded after N application. Any soluble ammonium-N-producing source can be used effectively under such conditions.

2. The rate of N release from SCU is slower under flooded than under drained conditions. However, a delay in flooding after N application results in a more rapid rate of release.

3. Evidence obtained in two experiments shows that cyclical foooding (flood-drain-flood) reduced the release rate of N from SCU, as compared with continuous flood. (Granules were recovered and analyzed for N.) This may result from formation of FeS on the coating surface, reducing the rate of urea dissolution.

4. In flooded systems, the release rate of urea from the larger size of SCU (based on -3+6 mesh urea) is slower than with the regular size (based on -6+10 mesh urea), even when the initial release rates (in H_2O) are equal. This indicates that the larger sized urea should receive a lighter coating than regular sized urea when it is to be applied to flooded rice.

5. Increasing the length of delay in flooding after planting decreased the yield of grain and straw. In one experiment, yields decreased as follows: flooding after 3 weeks > flooding after 6 weeks > flooding after 10 weeks ≥ no flooding. Delays in flooding apparently produce undesirable physiological effects as well as N losses.

Phosphate

1. Greenhouse studies were conducted to study the response of rice to rock phosphates varying widely in citrate solubility. The same series of rock phosphates prepared for the overseas experiments (described later) was tested in the greenhouse in comparison with TSP. The results showed a good relationship between citrate-soluble P

content of these various sources and growth response of rice. Furthermore, the agreement with field results in Thailand (same sources) was very good. Results indicated that the North Carolina rock phosphate was 95-90% as effective as granular triple superphosphate (TSP); central Florida, north Florida and Idaho rock phosphates were intermediate in effectiveness (30-46% as effective as granular TSP), while the Tennessee, Missouri, and Indian (Udaipur deposit) rocks were almost completely ineffective. These trends were similar for two successive crops. More details are provided in the appendix to the report entitled "Rock Phosphates for Flooded Rice," by O. P. Engelstad, January 1971.

2. Preliminary greenhouse results indicate that granulated urea-rock phosphate mixtures (26-13-0 and 18-18-0) are rather ineffective sources of P in the -6+9 mesh particle size. The rock phosphate (North Carolina deposit) was less effective when used in this manner than when added in finely ground form.

3. Granular-partially acidulated rock phosphate (North Carolina) was similar to the finely divided unacidulated North Carolina rock phosphate. Granular-partially acidulated central Florida rock phosphate was less effective than either of the above sources.

Zinc

1. The form of Zn does not appear to be as critical for correcting Zn deficiencies in paddy rice as for upland crops. For example, there is no evidence that organic carriers of Zn (chelated) have an agronomic advantage over less expensive inorganic carriers; in some greenhouse tests, chelated Zn has been less effective in terms of Zn uptake by rice.

2. Various macronutrient fertilizers have been granulated with sources of Zn. Most formulations are effective; the potential use of this approach for supplying Zn will depend upon prevailing cultural practices. For example, if Zn is to be applied with N fertilizer, it should be applied preplant or at least shortly after seeding or transplanting, since the main requirement for added Zn appears to be early in the growth cycle. However, this may not always correspond to the optimum time for N application.

3. Since the requirement for Zn is mainly during the early growth stage, placement of the Zn may be an important consideration. Greenhouse data show that Zn applied to seed, floodwater, or to the soil (shallow mixing) is equally effective for early growth. However, the effect of deep placement has not yet been determined.

4. Marked varietal differences in response to Zn have been noted in greenhouse experiments. As with many upland crops, excessive application rates of fertilizer P accentuated Zn deficiencies among the more susceptible varieties. Studies might be initiated in the tropics to determine those varieties more tolerant to Zn deficiency.

AGRONOMIC STUDIES OVERSEAS

As mentioned previously, the Advisory Committee assumed as one of its duties the evaluation of experimental fertilizers, with emphasis on field experiments. The program was initiated in mid-1969, and experiments have been conducted continuously since. Some of these locations have irrigation facilities which permit the growing of rice crops during the dry season in addition to the wet season. Except where indicated otherwise, high yielding varieties were used in all cases.

Yield data are presented here in the form received by TVA; some were submitted in kilograms per hectare, others in metric tons per hectare (mt/ha x 1000 = kg/ha).

Nitrogen

The first experiments evaluating SCU and other slow-release N sources on flooded rice were conducted in India and The Philippines during the wet season of 1969. These experiments were conducted under continuous flooding with careful water control, customary management technique at the better experiment stations. Sulfur-coated urea showed no advantage over conventional N sources under this system of water management. Since good water control is atypical in most developing countries, it was decided to use either delayed or intermittent flooding systems for the experiments with slow-release N sources. Losses of N from conventional fertilizers are generally serious under such conditions. Subsequently, experiments were conducted in India, The Philippines, Thailand, Peru, and Brazil that involved variations of such systems of water management.

India--The data from the 1969 experiments on N sources are presented in tables 1 and 2. While there was a good response to rates of added N in these experiments, there were no differences among sources, application methods, or times of application. Table 3 shows data from an experiment with various nitrification inhibitors. These were added to urea and applied with different methods of incorporation. However, no benefits of inhibitors were found. Data from two experiments conducted in India during the dry season of 1970 (winter-spring) are presented in table 4 and plotted in figures 1 and 2. The rate of N applied was 120 kg/ha in each case. The experiment at Garikapadu showed a consistent superiority of SCU over

Table 1. Effects of N source and application method on yield of rough rice. Rajendranagar, India, wet season, 1969

Incorporation	Source of nitrogen	Grain yield (kg/ha)
Control (no N)		3,381
No incorporation (100 kg N/ha)	Urea	5,005
	SCU[a]	5,191
	SCU[b]	4,881
	Urea + sulfur	5,034
Mean		5,028
Shallow incorporation (100 kg N/ha)	Urea	4,858
	SCU[a]	5,069
	SCU[b]	5,005
	Urea + sulfur	5,131
Mean		5,016
Deep placement (banded) (100 kg N/ha)	Urea	5,133
	SCU[a]	5,264
	SCU[b]	5,202
	Urea + sulfur	5,463
Mean		5,266
	LSD (sources)	N.S.
	CV(%)	1.9

[a]Dissolution rate = 24.1% in 5 days.
[b]Dissolution rate = 3.4% in 5 days.

LSD = Least significant difference at the 5% level of probability, CV(%) = coefficient of variation, N.S. = not significant.

Table 2. Effect of N source and time of application on yield of rough rice. Rajendranagar, India, wet season, 1969

N-source	Time and rate of N application: Tillering	Time and rate of N application: Panicle initiation	Grain yield (kg/ha)
Control (no N)	–	–	2,861
Urea	80		4,853
S-coated urea[a]	80		5,273
S-coated urea[b]	80		5.303
S-coated urea[a]	40 + 40x		5,029
S-coated urea[b]	40 + 40x		5,062
Urea	40	40	5,161
S-coated urea[a]	40	40	5,270
S-coated urea[b]	40	40	4,943
S-coated urea[a]	40	40x	5,194
S-coated urea[b]	40	40x	5,123
		LSD	343
		CV(%)	4.8

[a]Dissolution rate = 24.1% in 5 days.
[b]Dissolution rate = 3.4% in 5 days.

x As urea.

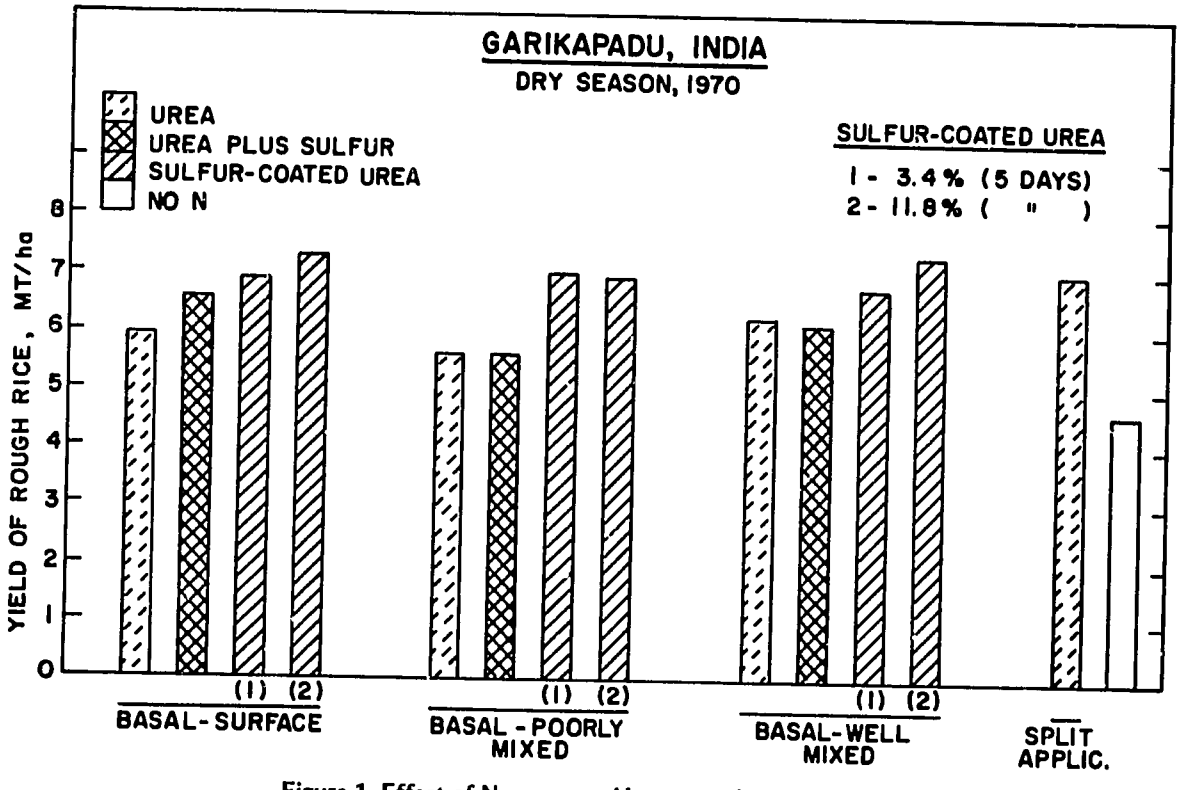


Figure 1. Effect of N source and incorporation method on the yield of rough rice with delayed flooding

Rice paddy being puddled in preparation for transplanting of rice on the Klong Luang Rice Experiment Station, Thailand.

Table 3. Summary of grain yield data from an experiment on methods of incorporating a basal dressing of urea in combination with various nitrification inhibitors; wet season, 1969. AICRIP, Rajendranagar, India

Method of incorporation	Source of nitrogen	Rate of inhibitor (kg/100 kg N)	Grain yield (kg/ha)
Control (no N)			3,373
No incorporation (100 kg N/ha)	Urea		4,886
	Urea + AM[a]	3.0	4,909
	Urea + ST[b]	3.0	4,721
	Urea + Cl 1580[c]	3.0	4,782
	Urea + N-serve[d]	2.0	4,678
Mean			4,795
Shallow incorporation (100 kg N/ha)	Urea		5,031
	Urea + AM	3.0	5,303
	Urea + ST	3.0	4,957
	Urea + Cl 1580	3.0	5,178
	Urea + N-serve	2.0	5,067
Mean			5,107
Deep placement (banded) (100 kg N/ha)	Urea		5,349
	Urea + AM	3.0	5,176
	Urea + ST	3.0	5,113
	Urea + Cl 1580	3.0	5,338
	Urea + N-serve	0.8	5,229
Mean			5,241
		LSD (sources)	396
		CV(%)	3.3

[a]'AM' is 2-amino-4-chloro-6-methyl pyrimidine; produced by Mitsui Toatsu of Japan.
[b]'ST' is 2 sulfanilamido thiazole (sulfathiazole); produced by Mitsui Toatsu of Japan.
[c]Cl 1580 is 2, 4-diamino-6-trichloromethyl triazine; produced by American Cyanamid.
[d]N-serve is 2-chloro-6-(trichloromethyl) pyridine; produced by Dow Chemical.

Table 4. Effect of N source and incorporation on the yield of rough rice (kg/ha). India, dry season, 1970

Method of incorporation	N source[a]	Locations: Garikapadu (Jaya)	Locations: Hyderabad (IR8)
None (surface)	Urea	5,991	4,446
	Urea + S[b]	6,546	4,262
	SCU_1[c]	6,819	6,451
	SCU_2	7,364	6,099
Shallow	Urea	5,672	5,547
	Urea + S	5,672	5,339
	SCU_1	7,009	7,262
	SCU_2	6,982	6,930
Well incorporated (Landmaster)	Urea	6,290	6,083
	Urea + S	6,109	6,037
	SCU_1	6,753	8,171
	SCU_2	7,364	7,816
Split application (Shallow incorp. of urea)		6,752	6,007
Control (no N)		4,610	2,256
	LSD (sources)	221	978
	CV(%)	3.1	7.2

[a]All N sources applied at 120 kg N/ha.
[b]Finely divided sulfur added to determine any response to S.
[c]SCU_1–dissolution rate in H_2O of 3.4% in 5 days.
SCU_2–dissolution rate in H_2O of 11.8% in 5 days

Table 5. Effect of N source and application time on yield of IR8. India, dry season, 1970

Source[a]	Time of application (kg/ha): Basal	Tillering	Panicle initiation	Boot stage	Rough rice yield kg/ha
Urea	0	100	0	0	6,298
SCU_1[b]	0	100	0	0	6,572
SCU_2	0	100	0	0	6,581
Urea	0	60	40	0	6,513
SCU_1	0	60	40	0	6,167
SCU_2	0	60	40	0	6,439
SCU_1	0	60	40[c]	0	6,790
SCU_2	0	60	40[c]	0	6,485
SCU_1	0	60 + 40[c]	0	0	6,436
SCU_2	0	60 + 40[c]	0	0	6,514
Urea	50	25	25	0	6,451
Urea	30	40	30	0	6,315
Urea	20	40	20	20	6,538
Urea	0	40	40	20	6,368
Control (no N)					2,772
				LSD	790
				CV(%)	9.1

[a]All N sources added at a rate of 100 kg N/ha
[b]SCU_1–dissolution rate in H_2O of 3.4% in 5 days.
SCU_2–dissolution rate in H_2O of 11.8% in 5 days.
[c]N added as uncoated urea

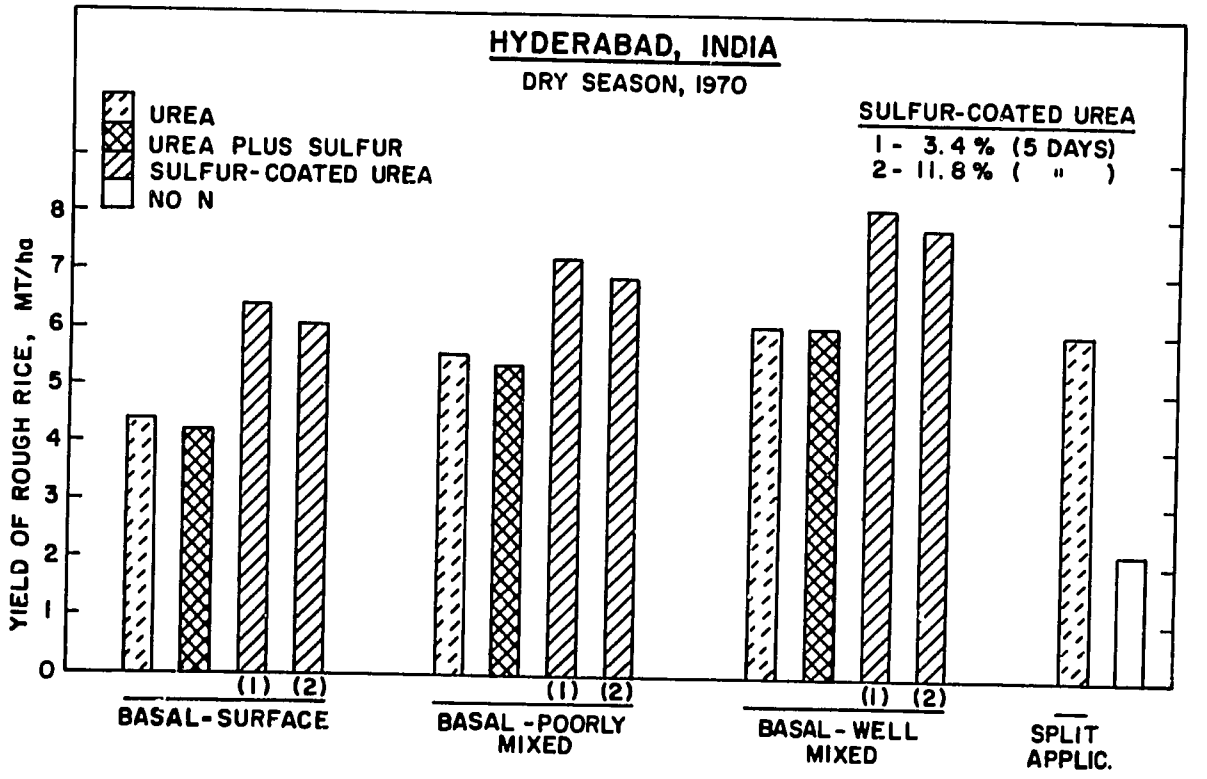


Figure 2. Effect of N source and incorporation method on the yield of rough rice with delayed flooding

Table 6. Effect of N source, rate, and time of application on the yield of rough rice (kg/ha), India, 1970

Source	Application method	N rate kg/ha	Locations			
			Varanasi	IARI	Tjanjavur	Mangalore
SCU[a]	Basal	50	5,104	6,132	5,447	4,701
		100	5,797	6,929	6,097	4,757
Urea	Basal	50	4,682	5,627	5,072	4,357
		100	6,163	6,309	5,849	4,547
Urea	Split	50	4,362	5,866	5,488	4,547
		100	6,024	6,621	6,570	4,664
No N	–	0	2,827	4,463	4,185	3,759

[a]Average results from two SCU materials differing in dissolution rates.

Table 7. The effect of N source and incorporation on the yield of rough rice (kg/ha). India, dry season, 1972

N source[a]	No incorporation	Incorporated (trampling)
Urea	6,150	6,764
SCU	6,960	8,640
Shellac-coated urea	5,875	7,935
Urea, split applied	7,726	7,563
Control (no N)	3,566	3,536

[a]All N sources applied at a rate of 125 kg N/ha.

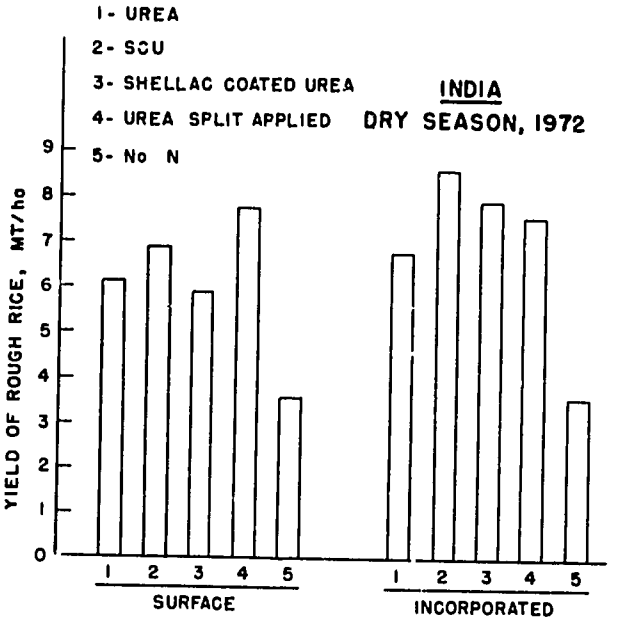


Figure 3. Effect of N source and incorporation on the yield of rough rice. All N sources added at the rate of 125 kg N/ha

uncoated urea, regardless of the type of application. No effect of incorporation was noted. The experiment at Hyderabad showed a marked increase in yield for the SCU materials over that from straight urea; all materials showed increases in yield with better incorporation. The yield from well-incorporated urea equaled the yield from split applications of urea. These experiments were conducted with a delay in flooding of about 8 days after fertilizer application. The results obtained would indicate a very rapid rate of hydrolysis and possibly nitrification. Since the soil pH at Hyderabad is about 8.0, some atmospheric losses of NH_3-N could have occurred from the surface or poorly mixed applications. However, it seems that some nitrification may also have occurred at both locations during the period of 8 days. This would account for the superiority of SCU even when well mixed with the soil. An experiment with times of application of urea and SCU was conducted in the dry season of 1970. These data are shown in table 5. An excellent response to N was obtained; however, no differences among sources or times of application were obtained.

Uniform experiments were conducted at four different locations in India in which two SCU materials were compared with basal-applied and split-applied urea. The data obtained are given in table 6. The results show no definite pattern; SCU was superior in two experiments, split-applied urea was superior in one, with SCU and urea about equal in the last.

Various N sources, including urea, SCU, and shellac-coated urea (Indian product), were compared at a rate of 125 kg N/ha in connection with surface and incorporated methods of application during the dry season of 1972. The results are shown in table 7 and plotted in bar-graph form in figure 3. With surface application the treatments decreased in effectiveness in the following order: urea (split) > SCU > urea > shellac-coated urea > no N.

Table 8. The effect of N source, rate, and time of application on the yield of rough rice. India, dry season, 1972

N source	Rate of N kg/ha	Grain yield kg/ha
Urea	0	2,024
	50	3,998
	75	4,715
	100	5,415
	125	6,824
	150	7,364
	175	7,969
	200	8,682
SCU	125	7,814
Shellac-coated urea	125	7,057
Urea, split applied	125	6,327
Control (no N)	0	2,021

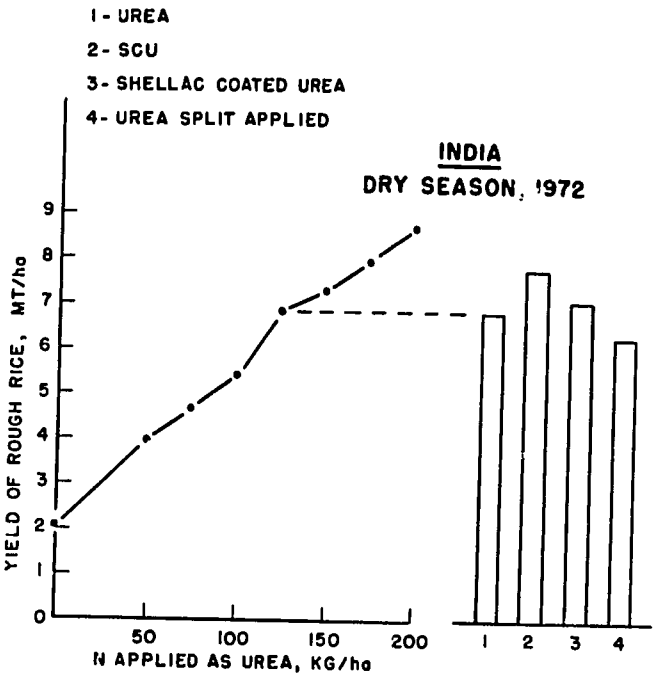


Figure 4. Effect of N source and rate (urea) on the yield of rough rice. Sources shown in bars were applied at 125 kg N/ha

The following order occurred as a result of incorporation: SCU > shellac-coated urea > urea (split) > urea > no N.

In both cases SCU outyielded uncoated urea and shellac-coated urea; with incorporation, SCU also outperformed split-applied urea.

The results of a companion experiment with these same sources are presented in table 8 and plotted in figure 4. Urea was added at various rates from 0 to 200 kg N/ha; other sources were added at 125 kg N/ha. The treatments decreased in effectiveness as follows: SCU > shellac-coated urea > urea > urea (split).

A third experiment was conducted during the 1972 dry season in India to compare various times of application of urea-N. However, SCU and shellac-coated urea were also included as basal treatments. The results presented in table 9 show that SCU outyielded all other treatments.

Data from an extensive program of evaluation in India in 1971 have not yet been received. These data should prove quite useful.

Table 9. The effect of N source and time of application on yield of rough rice. India, dry season, 1972

N Source	Total N kg/ha	Basal	Early tillering	Late tillering	Panicle initiation	Boot stage	Heading stage	Grain yield kg/ha
Urea	120	120						5,729
	120	80	40					5,799
	120	80		40				6,109
	120	80			40			5,947
	120	80				40		4,853
	120	80					40	4,696
	120	30	20	35	35			5,801
	120	30		40	30	20		5,449
	120	60		30	30			5,935
SCU	120	120						7,127
Shellac-coated urea	120	120						6,482
Control (no N)								1,964

Table 10. Effect of N source and rate on yield of rough rice. The Philippines, wet season, 1969

Nitrogen sources	Rate of N kg/ha	Grain yield: Los Banos kg/ha	Grain yield: Dagupan City kg/ha
Ammonium sulfate	25	5,940	3,727
	50	5,438	4,076
	75	6,123	4,441
	100	6,258	4,650
Urea	25	5,584	3,742
	50	6,186	4,239
	75	6,484	4,564
	100	6,247	4,642
Sulfur-coated urea[a]	25	5,908	3,924
	50	5,879	4,396
	75	6,545	4,462
	100	6,229	4,564
Sulfur-coated urea[b]	25	6,024	3,860
	50	4,850	4,186
	75	6,267	4,342
	100	6,000	4,316
Isobutylidene diurea	25	5,874	3,922
	50	5,954	4,240
	75	5,930	4,388
	100	6,247	4,483
Crotonylidine diurea	25	5,463	3,662
	50	5,486	4,602
	75	6,161	4,636
	100	6,135	4,647
No N	0	5,151	3,417

[a]Dissolution rate = 5.5% in 10 days.
[b]Dissolution rate = 40.8% in 10 days.

The Philippines—The data from the experiments in 1969 are presented in table 10. While yield response was adequate, there were no significant differences in effectiveness among sources. Experiments were conducted during both the dry and wet season of 1970 to compare several N sources under various water management systems. However, a series of four typhoons struck the experimental locations during growth, resulting in low yields that are of little value in comparing fertilizers. These data are presented in tables 11 and 12 without further comment.

Additional experiments were conducted in 1971; the data obtained are shown in tables 13 and 14. In addition to source comparisons, timing and planting methods were also evaluated. The data in table 13 were obtained during the dry season of 1971. While SCU was slightly superior to all other sources for basal dressing for broadcast seeding, it was no better than other sources for basal dressing for the transplanting method; for split applications, SCU was inferior to other sources for both planting methods

Table 14 presents data from the same sources as above under both continuous flooding (irrigated) and rainfed conditions. Yield response was not very great in either system. Differences in responses among sources were generally insignificant.

Thailand—Two identical experiments were conducted in Thailand during 1970 and repeated in 1971 to compare SCU, urea, and ammonium sulfate under basal and split applications. The data obtained are shown in table 15 and plotted in figures 5 and 6. Response to added N was not obtained at the Surin station in 1970; however, good yield responses were obtained at Ubon in 1970 and at both

Table 11. Effect of N source, rate, and application time on the yield of rough rice (mt/ha). IRRI, The Philippines, wet season, 1970

Source[b]	Continuous flood: Basal dressing	Continuous flood: Top-dressing[a]	Rainfed (puddled): Basal dressing	Rainfed (puddled): Top-dressing[a]
Ammonium sulfate	3.1	3.3	3.0	3.5
Urea	3.2	3.3	3.2	3.5
Ammonium sulfate nitrate	3.1	3.2	3.3	3.2
Calcium ammonium nitrate	3.2	3.2	3.1	3.6
SCU[c]	3.0	3.2	3.2	3.7
SCU[d]	2.9	3.3	3.3	3.6
IBDU	2.9	3.5	3.2	3.5
Control (no N)	2.6		2.8	

[a]Split between maximum tillering and panicle initiation stages.
[b]All sources added at a rate of 60 kg/ha.
[c]Dissolution in H_2O–20% in 7 days.
[d]Dissolution in H_2O–10% in 7 days.

Table 12. Effect of N source, rate, and application time on the yield of rough rice (mt/ha). IRRI, The Philippines, wet season, 1970

Source	Rate applied kg N/ha	Continuous flood			Rainfed (puddled)		
		L[a]	MT–PI	MT–PI–B	L	MT–PI	MT–PI–B
Ammonium sulfate	40	3.5	3.8	4.0	3.1	3.5	3.6
	80	3.8	3.3	4.2	3.4	2.8	3.0
Urea	40	3.4	4.2	3.7	3.3	3.4	3.6
	80	3.4	3.9	3.9	3.3	3.2	3.4
Ammonium sulfate nitrate	40	3.7	3.9	3.9	3.1	3.4	4.2
	80	3.5	3.7	4.2	3.4	3.0	3.3
Calcium ammonium nitrate	40	3.4	3.8	4.0	3.4	3.4	3.2
	80	3.1	4.0	4.2	3.5	3.1	3.3
SCU[b]	40	3.6	4.2	4.2	3.4	3.2	3.1
	80	2.6	4.2	3.7	3.3	3.4	3.4
SCU[c]	40	–	3.5	3.5	–	3.4	3.3
	80	–	3.8	3.8	–	3.5	3.2
IBDU	40	2.8	3.9	3.9	2.9	3.7	3.4
	80	2.3	4.1	4.4	2.2	3.3	3.5
Control	0	3.3			3.2		

[a]N application times: L–during land preparation; MT–at maximum tillering, PI–at panicle initiation; B–at booting time.
[b]Dissolution in H_2O–21% in 7 days.
[c]Dissolution in H_2O–4% in 7 days.

Table 13. Effect of N source, application time, and planting method on yield of rough rice (mt/ha). IRRI, The Philippines, dry season, 1971

Source[a]	Broadcast seeding		Transplanted	
	Single application	Split application	Single application	Split application
		continuous flooding		
Ammonium sulfate	6.1	8.6	7.3	8.2
Urea	7.6	8.7	7.4	8.1
SCU[b]	8.4	8.2	7.5	6.6
IBDU	7.8	9.1	7.9	8.0
Calcium ammonium nitrate	7.2	8.6	7.1	8.0
Ammonium sulfate nitrate	6.6	8.5	7.4	8.2
No N	5.5		4.6	

[a]All applied at 150 kg N/ha.
[b]Average results from four SCU materials with 6, 11, 18, and 22% dissolution rates (2 weeks).

stations in 1971. Yield levels were rather low, however; maximum yields were in the neighborhood of 3-4 mt/ha.

At Ubon in 1970, basal-applied urea appeared to be slightly less effective than the other treatments. No other differences are apparent. In 1971, the results at the Surin station showed basal- and split-applied SCU to be equal in effectiveness and superior to urea (basal or split) and to ammonium sulfate added in split applications. The highest yield was obtained from ammonium sulfate applied as basal dressing.

The Ubon results in 1971 showed basal-applied SCU superior to split-applied SCU; the reverse was true for urea and for ammonium sulfate. The basal-applied SCU and ammonium sulfate added as split applications were the two highest yielding treatments in the experiment.

Table 14. Effect of N source, application time, and planting method on yield of rough rice (mt/ha). IRRI, The Philippines, wet season, 1971

Source[a]	Broadcast seeding		Transplanted	
	Single application	Split application	Single application	Split application
		continuous flooding		
Ammonium sulfate	6.5	5.5	6.4	6.5
Urea	6.2	6.3	6.5	6.5
SCU[b]	6.4	6.0	6.5	6.4
IBDU	6.1	5.6	6.4	6.4
Calcium ammonium nitrate	5.8	6.4	5.9	6.1
Ammonium sulfate nitrate	5.9	5.5	6.1	6.5
No N	5.1		5.2	
		rainfed paddy (lowland)		
Ammonium sulfate	5.6	5.0	6.1	6.6
Urea	5.7	6.2	6.3	6.2
SCU[b]	5.6	5.8	6.1	6.2
IBDU	5.3	5.3	5.8	6.1
Calcium ammonium nitrate	5.4	5.8	5.9	6.2
Ammonium sulfate nitrate	5.6	5.6	6.0	6.4
No N	5.0		5.3	

[a]All applied at 80 kg N/ha.
[b]Average results from four SCU materials with 6, 11, 18, and 22% dissolution rates (2 weeks).

Table 15. Effect of N source and time of application on yield of rough rice at two locations in Thailand. Kg/ha

Source	Rate of N applied, kg/ha		Surin		Ubon	
	Transplanting	Topdressing	1970	1971	1970	1971
SCU	80	–	2,613	3,193	3,467	3,500
SCU	40	40	2,686	3,182	3,364	3,167
Urea	80	–	2,656	2,433	3,136	2,601
Urea	40	40	2,636	2,684	3,536	3,221
Ammonium sulfate	80	–	2,569	3,416	3,660	2,423
Ammonium sulfate	40	40	2,688	2,739	3,582	3,542
No N	–	–	2,547	1,582	1,599	1,730
		LSD	N.S.	174	378	334

Peru—Most of the rice is produced in a dry coastal area in the northern part of the country. The soils are high in pH and often saline. Water for growing rice is obtained from rivers originating in the Andes Mountains to the east. The typical water management system is that of intermittent flooding. The flooding-drying sequences are rather short, permitting a number of cycles during the growing period of the rice. The paddies are not puddled and water infiltration rates are high.

A number of experiments have been conducted in this area to evaluate SCU and urea as sources of N. These experiments included SCU as a basal dressing and urea applied both as a basal dressing and as a topdressing. Rates of N applied ranged as high as 400 kg N/ha.

The data obtained from these experiments are presented in tables 16-18 and plotted in figures 7-11. The experiments at Tavara (figure 7) and at Jequetepeque (figure 9) show the greatest benefits from coating urea. In both cases, SCU

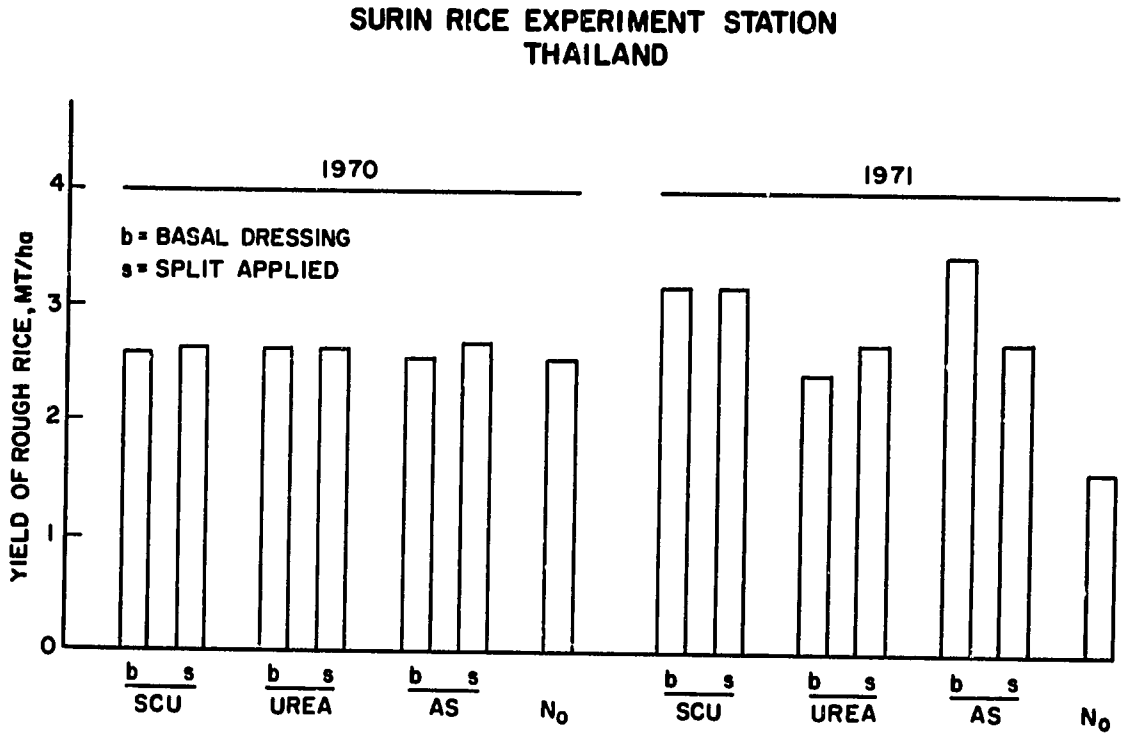


Figure 5. Effect of N source and time of application on yield of rough rice. All sources were applied at a rate of 80 kg N/ha

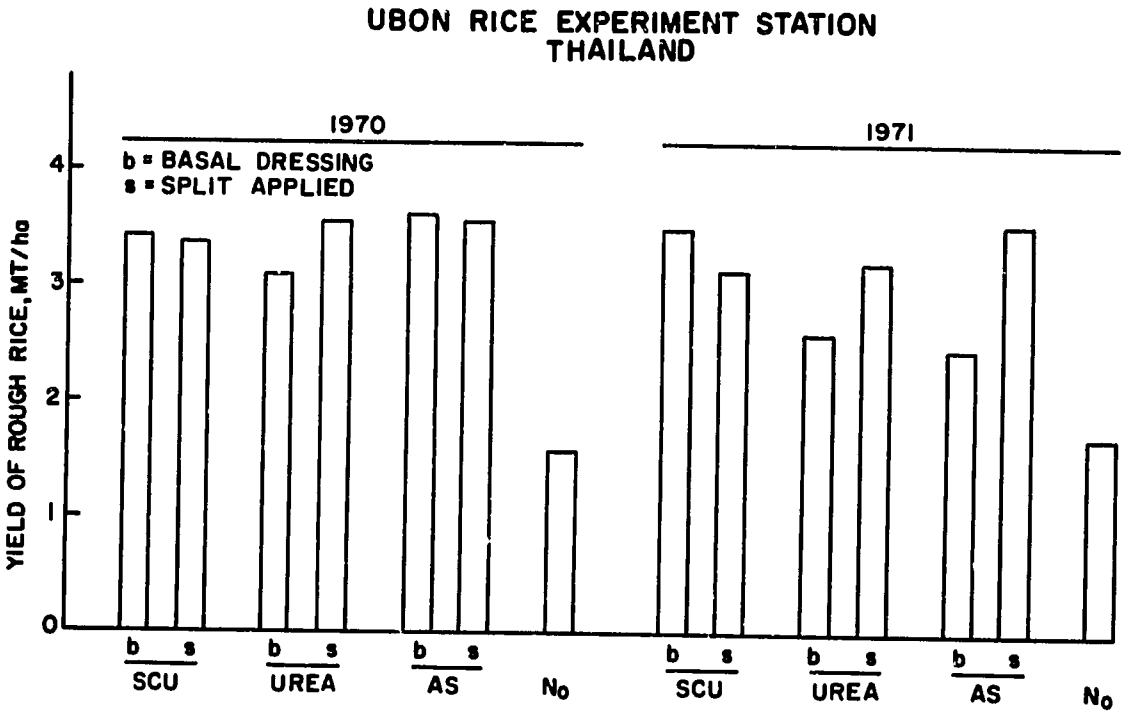


Figure 6. Effect of N source and time of application on yield of rough rice. All sources were applied at a rate of 80 kg N/ha

Table 16. Effect of N source, rate, and application method on the yield of rough rice. Tavara, Peru, 1969-70

Source	Application method	Rate of N kg/ha	Grain yield kg/ha
SCU[a]	Basal	80	4,570
		160	5,731
		240	6,611
		320	7,203
SCU[b]	Basal	80	3,904
		160	6,583
		240	5,748
		320	6,878
SCU–urea(½-½)	Basal	80	3,970
		160	5,763
		240	6,432
		320	6,369
Urea	Basal	80	3,948
		160	4,804
		240	5,154
		320	5,291
Urea	Topdressed	80	3,450
		160	4,672
		240	4,217
		320	5,609
No N		–	2,213
		LSD (sources)	506
		CV(%)	17.7

[a]18.7% dissolution rate in 7 days.
[b]31.6% dissolution rate in 7 days.

Table 17. Effect of N source, rate and application method on the yield of rough rice. Bagua, Peru, 1970-71

Source	Application method	Rate of N kg/ha	Grain yield kg/ha
SCU[a]	Basal	40	7,413
		80	8,373
		120	9,368
		160	9,328
		200	9,460
SCU[b]	Basal	40	7,303
		80	8,373
		120	9,215
		160	9,208
		200	9,180
Urea	Basal	40	6,033
		80	7,150
		120	8,103
		160	8,413
		200	8,753
Urea	Topdressing	40	6,913
		80	8,055
		120	8,693
		160	9,103
		200	9,400
No N		–	4,825
		LSD (sources)	.301
		CV(%)	8.2

[a]0.6–1.2% daily dissolution rate.
[b]1.6–2.2% daily dissolution rate.

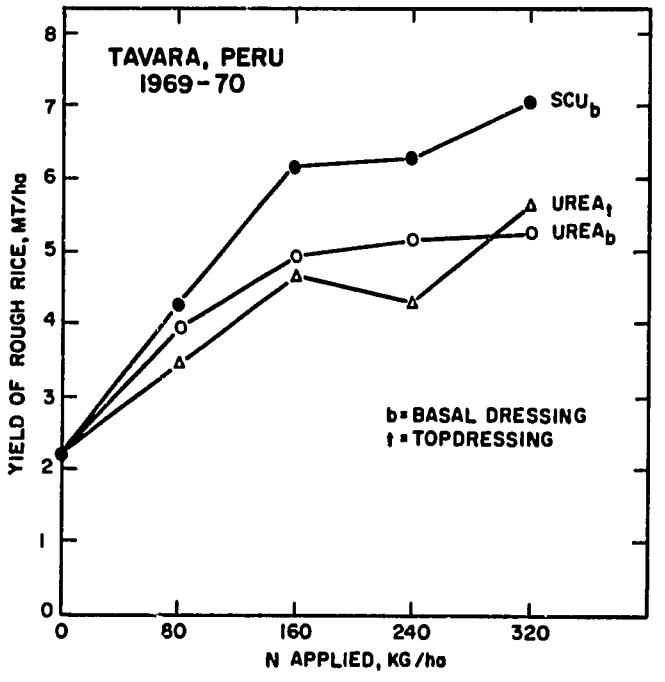


Figure 7. Yield of rough rice as affected by source, rate, and time of application of N with intermittent flooding

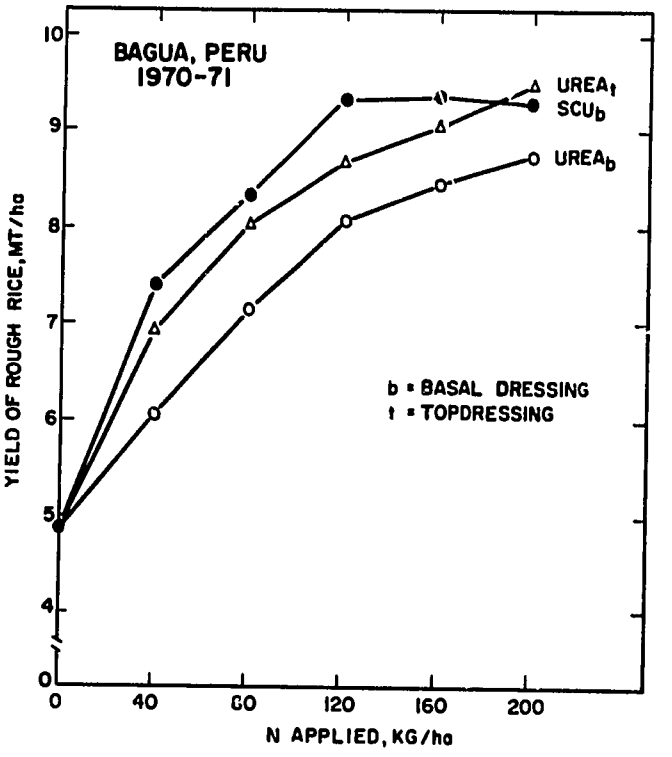


Figure 8. Yield of rough rice as affected by source, rate, and time of application of N with intermittent flooding

Table 18. Effect of N source, rate and application method on the yield of rough rice. Peru, 1970-71

Source	Application method	Rate of N kg/ha	Yield of grain: Jequetepeque mt/ha	Cienego: IR8 mt/ha	Cienego: Minabir mt/ha	Vista Florida: Continuous mt/ha	Vista Florida: Intermittent mt/ha
SCU[a]	Basal	80	6.7	7.2	6.8	9.7	9.7
		160	8.4	8.9	6.6	11.4	10.3
		240	10.3	9.4	5.4	10.7	10.0
		320	10.9	9.2	5.4	9.9	10.1
		400	10.9	8.7	2.2	9.9	10.5
SCU[b]	Basal	80	5.5	7.2	5.2	9.2	9.0
		160	7.1	9.0	7.0	11.0	10.5
		240	9.5	9.5	6.3	10.7	10.4
		320	9.7	9.1	3.6	11.2	9.3
		400	10.2	8.4	1.7	9.2	9.4
Urea	Basal	80	4.4	5.7	5.1	8.6	8.2
		160	4.2	6.8	5.7	10.0	8.3
		240	5.7	7.3	6.0	9.9	9.1
		320	7.6	8.0	5.8	9.5	9.8
		400	6.8	8.8	3.4	10.1	9.7
Urea	Topdressing	80	5.1	6.4	2.9	9.8	8.7
		160	5.2	8.1	6.2	10.1	9.8
		240	6.2	8.4	7.0	11.0	10.8
		320	7.3	10.1	6.4	11.3	10.4
		400	7.7	9.6	5.9	11.5	10.5
No N		–	3.9	4.2	3.6	7.2	6.8
		LSD (sources)	0.6	0.4	0.4	0.4	0.4
		CV(%)	12.3	8.2	8.2	8.0	8.0

[a]0.6–1.2% daily dissolution rate.
[b]1.6–2.2% daily dissolution rate.

was markedly superior to urea applied either as a basal or as a topdressing treatment. The wide differences in yield and net return persisted over all rates. At Cienego, however, (figure 10) SCU was superior only at the lower rates. Above 240 kg of N, topdressed urea was the superior treatment. The same general pattern was true for the Bagua experiment (figure 8) and for the Vista Florida experiment (figure 11). For these locations, SCU produced the same yield with substantially less N.

These results indicate that serious losses of urea-N occur from these soils. Upon nitrification, nitrate-N is probably lost by leaching and/or denitrification.

Brazil—Yield data from two experiments conducted in the State of Sao Paulo are presented in table 19. One experiment was established on lowland (flooded) rice, the other on upland rice. There were significant responses to added N in both cases; however, the yield levels in the lowland experiment were substantially higher than those from the upland. The highest rate employed in the upland experiment decreased yields consistently for all N sources. Differences among sources were not significant in these experiments.

Interpretation of Data on N Sources

As a means of summarizing the data from the above experiments, relative agronomic effectiveness values were calculated (urea applied as a basal dressing = 100) for all experiments in which a significant response to applied N occurred; these were compiled in table 20. Out of a total of 56 comparisons, 46 showed SCU to be superior to urea when both were applied as a basal treatment. There were 19

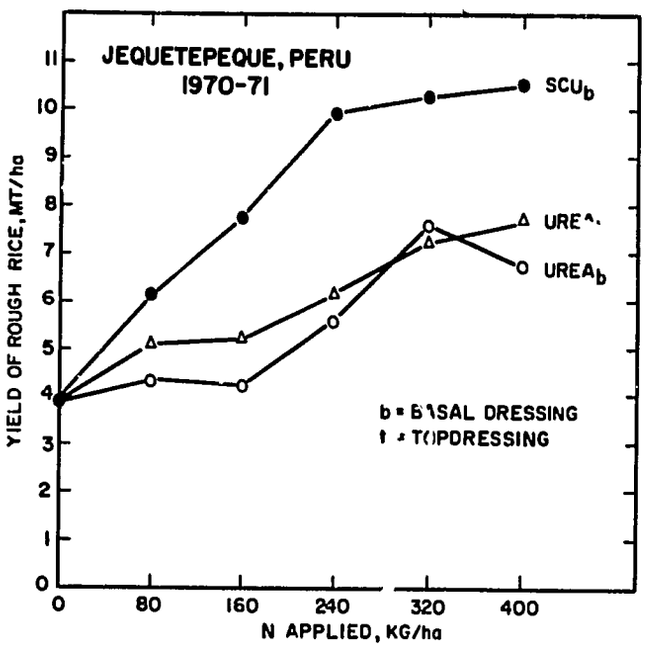


Figure 9. Yield of rough rice as affected by source, rate, and time of application of N with intermittent flooding

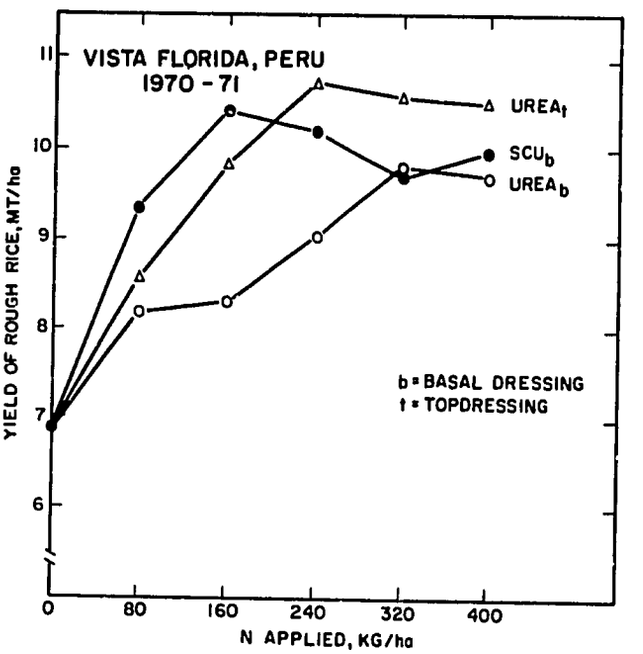


Figure 11. Yield of rough rice as affected by source, rate, and method of application of N with intermittent flooding

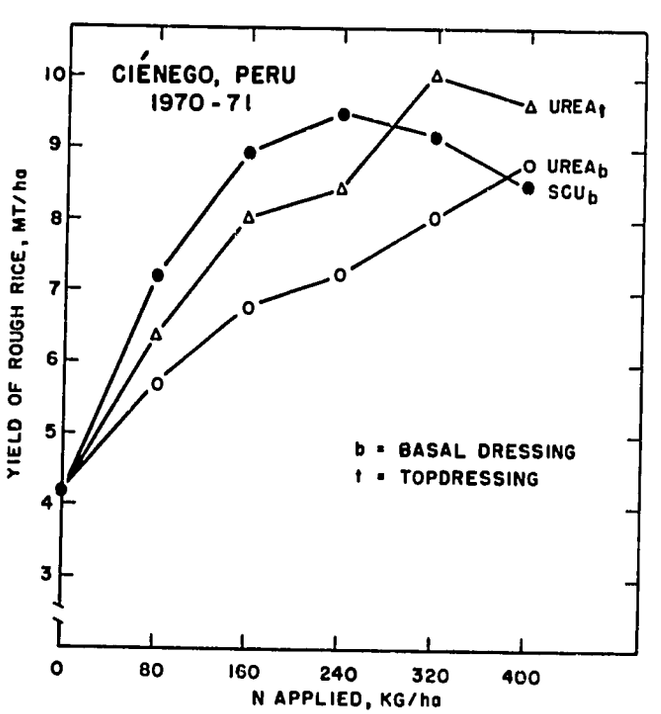


Figure 10. Yield of rough rice as affected by source, rate, and time of application of N with intermittent flooding

comparisons (Asian countires) where urea was applied as a split application, i.e., part applied at planting time and the remainder later as a topdressing. Of these 19 comparisons, 12 showed SCU to be superior to split-applied urea. Five experiments in Peru included treatments in which all of the urea was added as topdressing. Basal-applied SCU was superior to topdressed urea in 19 out of a total of 26 comparisons.

These results indicate a low effectiveness of urea-N in flooded rice systems. Losses are apparently severe in many cases, particularly where flooding is not continuous after fertilizer application. Temporary drainage permits nitrification to occur–resulting in leaching and/or denitrification upon reflooding. Coating of urea (as in SCU) results in increased utilization of the applied N; apparently the quantity of soluble N available for nitrification is lower from SCU than from uncoated urea at any given time.

It is rather surprising that SCU often performs as well or better than split application or topdressing. The explanation for this may lie in the difficulty of applying N at proper times during the growing period.

To provide a comparison with U.S. results, table 21 presents the relative agronomic effectiveness values for a number of domestic experiments. For the most part, delayed flooding was employed in connection with drill

In Peru, rice grown under intermittent flooding produced about 2½ more tons per hectare with sulfur-coated urea (right) than with uncoated urea (left).

seeding. However, there was one experiment in Arkansas (1970) where intermittent flooding also occurred. The effectiveness of basal applied urea was very low in this experiment.

Finally, the net returns to these various sources were calculated for each rate of N employed in the overseas experiments. Also calculated was the return per dollar invested in coating (SCU); these are found in table 22. Prices for rice and for urea N were estimated for these countries using whatever evidence was available. The first column shows the ratios of net returns (over fertilizer cost) from SCU and urea, both applied as basal dressings. The second column shows the ratios of net returns from SCU and urea, when the latter is applied as split application. The third column shows ratios of net returns when urea is topdressed. In view of the possibility that these estimates may be inaccurate, it should be pointed out that the objective here is to provide information of more qualitative nature than quantitative.

Table 19. Effect of N source, rate, and water management on yield of rough rice. Brazil, 1972

	Lowland rice		Upland (rainfed) rice	
Source	N rate kg/ha	Yield kg/ha	N rate kg/ha	Yield kg/ha
SCU[a]	50	3,510	25	2,244
	100	4,118	50	2,817
	150	4,174	100	1,609
Urea	50	3,277	25	2,355
	100	3,604	50	2,809
	150	4,266	100	1,302
Urea + S	50	3,344	25	1,946
	100	3,817	50	2,639
	150	4,277	100	1,455
AS	50	3,884	25	2,194
	100	3,833	50	2,997
	150	4,195	100	1,886
No N	0	2,293	0	1,220
	LSD (sources)	N.S.		N.S.
	CV(%)	10.6		17.6

[a]Average of yields from two SCU materials of 22.5 and 14.2% dissolution rate in 7 days.

Phosphate

Since the first meeting of the Advisory Committee, several members have shown a good deal of interest in comparing various phosphates for rice grown on acid soils. The main objective was to determine whether satisfactory alternatives existed that might be cheaper than the acidulated phosphates. Accordingly, TVA acquired and characterized a substantial supply of various finely ground U.S. rock phosphates varying widely in citrate solubility. The P contents and citrate solubility data are given in table 37 for the various rock phosphates used. These phosphates formed the test series supplied to the overseas cooperators; however, these cooperators were encouraged to add locally available rock phosphates to the experiments where desired.

The experiments in Thailand and Ceylon were conducted under the general coordination of S. K. De Datta at the IRRI in The Philippines. All other experiments were coordinated directly between the cooperator and TVA.

India—Experiments were conducted at four locations in India to compare TSP, ordinary superphosphate (OSP) and the various rock phosphates described above. The sources and rates employed and the results obtained at Hyderabad are shown in table 23. The soil pH at Hyderabad was very high (near 8.0); not surprisingly, the yield response to the water-soluble phosphates was very marked

Table 20. Relative agronomic effectiveness of N sources (response to urea = 100). Summary of overseas data

Country	Location	Year	Rate of N kg/ha	SCU_b	$Urea_b$	$Urea_s$	$Urea_t$
India	Rajendranagar	1969	100	100	100	–	–
	Garikapadu	1970	120	170	100	149	–
	Rajendranagar	1970	120	161	100	124	–
	Varanasi	1970	50	123	100	83	–
			100	89	100	96	–
	IARI	1970	50	143	100	121	–
			100	134	100	117	–
	Tjanjavur	1970	50	142	100	147	–
			100	115	100	143	–
	Mangalore	1970	50	158	100	132	–
			100	127	100	115	–
	Rajendranagar	1972	125	146	100	141	–
	Rajendranagar	1972	125	121	100	90	–
	Rajendranagar	1972	120	137	100	103	–
Philippines	Los Banos	1969	a	83	100	–	–
	Dagupan City	1969	a	95	100	–	–
	Los Banos	1971	150	120	100	136	–
	Los Banos	1971	80	100	100	100	–
	Los Banos	1971	80	80	100	120	–
Thailand	Ubon	1970	80	122	100	126	–
	Ubon	1971	80	203	100	171	–
	Surin	1971	80	189	100	129	–
Peru	Tavara	1969-70	80	119	100	–	71
			160	150	100	–	95
			240	139	100	–	68
			320	150	100	–	110
	Bagua	1970-71	40	210	100	–	173
			80	153	100	–	139
			120	136	100	–	118
			160	124	100	–	119
			200	114	100	–	116
	Jequetepeque	1970-71	80	457	100	–	252
			160[b]	357	100	–	118
			240	344	100	–	130
			320	173	100	–	93
			400	233	100	–	133
	Cienego (IR8 only)	1970-71	80	201	100	–	147
			160	183	100	–	150
			240	170	100	–	137
			320	129	100	–	153
			400	96	100	–	119
	Vista Florida (Continuous flooding)	1970-71	80	157	100	–	186
			160	143	100	–	104
			240	130	100	–	148
			320	148	100	–	178
			400	79	100	–	148

Table 20. (continued)

Country	Location	Year	Rate of N kg/ha	SCU_b	$Urea_b$	$Urea_s$	$Urea_t$
	Vista Florida (Intermittent flooding)	1970-71	80	186	100	–	136
			160	240	100	–	200
			240	148	100	–	174
			320	97	100	–	120
			400	110	100	–	128
Brazil	Sao Paulo (Lowland rice)	1972	50	120	100	–	–
			100	129	100	–	–
			150	95	100	–	–
	Sao Paulo (Upland rice)	1972	25	110	100	–	–
			50	106	100	–	–
			100[c]	–	–	–	–

[a]Yields were averaged over 25, 50, 75, and 100 kg N/ha.
[b]For the calculations in this table and table 22, a yield of 5.0 mt/ha was assumed for 160 kg N/ha applied as basal applied urea at Jequetepeque. This value, chosen by interpolation, avoids unrealistic results obtained with use of the original yield observation.
[c]Yield depression at 100 kg N/ha.

Subscripts in column headings refer to method of application: b = basal; s = split application; t = topdressing.
Note: The above values were calculated as follows:

$$\frac{\text{Yield response (over check)}}{\text{Yield response (over check) from urea}_b} \times 100$$

at this location while the rock phosphates were quite ineffective. This is shown quite clearly in figure 12 for the wet season in 1970. Also, residual effects of the water-soluble phosphates for later crops were quite satisfactory.

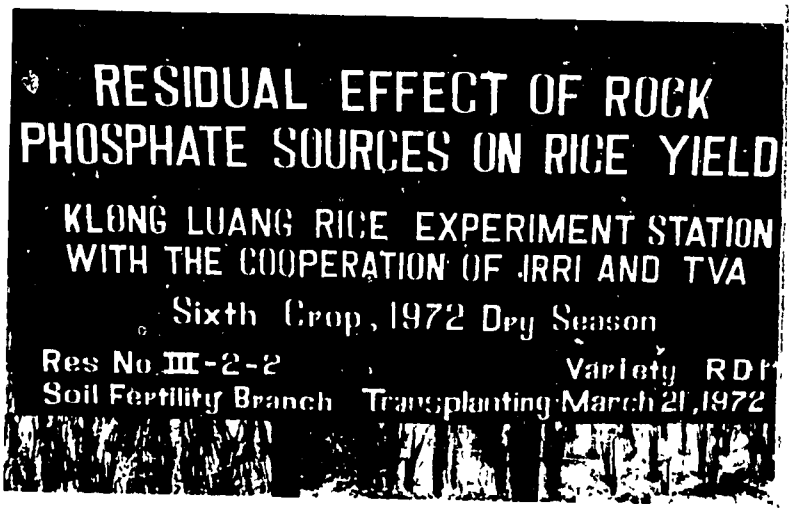
The results of other experiments at Bhubaneswar, Karamana, and Moncompu (see table 24) show no response to any of the phosphates applied. The soil pH at these latter locations varied between 5.1 and 5.3, which indicates sufficient acidity to solubilize rock phosphate. With no response to any of the phosphates, one can only conclude that soil P was adequate for the yield levels attained. The yields at Bhubaneswar were rather low; however, the yields at Karamana and Moncompu range between 4,500 and 6,000 kg/ha, which are quite satisfactory yield levels.

The Philippines—One experiment was conducted to compare phosphate sources on a soil of pH 4.8 in Bulacan, northeast of Manila. There was a visual response in growth and tillering to TSP early in the growth period; however, the yield data presented in table 25 show little or no yield response to any of the sources. Apparently there was sufficient available P in the soil for normal yields.

Thailand—The greatest amount of research on phosphate sources was conducted in Thailand. This was a joint effort by the Rice Department, the IRRI and TVA.

The first experiments were established in the wet season, 1969. One was at Klong Luang Rice Experiment Station on an acid sulfate soil of moderate acidity (pH 4.6); the

An experiment on an acid sulfate soil on the Klong Luang Rice Experiment Station, Thailand; cropping was continued beyond the first season to measure residual effects of phosphate sources.



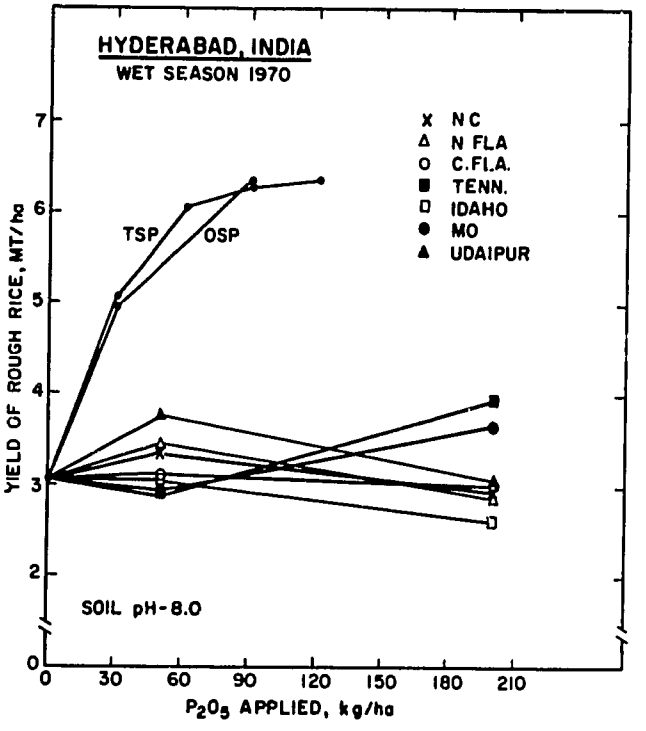


Figure 12. Effect of various phosphorus sources on the yield of rough rice

Table 21. Relative agronomic effectiveness for N sources compared for flooded rice: summary of U.S. results. (delayed flooding used in all cases)

Location	Year	Source[a]		
		SCU_b	$Urea_b$	$Urea_t$
Louisiana	1967	92	100	–
	1968	95	100	–
	1969	112	100	–
	1970	113	100	–
Texas	1970	109	100	–
	1971	100	100	–
California	1969	88	100	–
	1969	102	100	–
	1969	207	100	–
	1970	156	100	–
	1970	173	100	–
	1970	114	100	–
	1971	96	100	–
Arkansas	1967	111	100	104
	1967	110	100	93
	1968	147	100	132
	1969	118	100	90
	1970	326	100	296
	1971	104	100	86
	1971	156	100	195
	1971	280	100	50

[a]b = basal dressing; t = topdressing

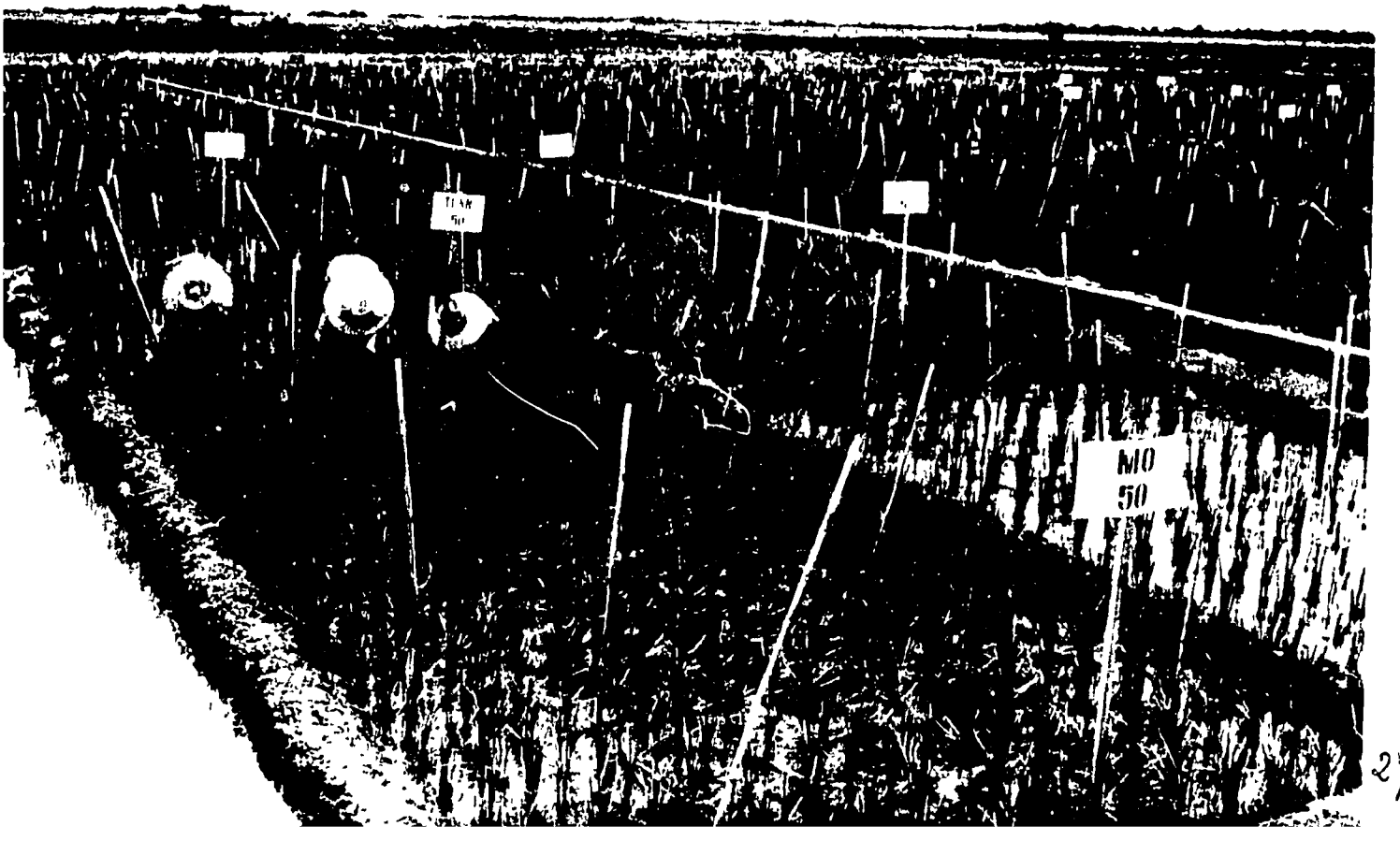


Table 22. Returns per dollar invested in coating urea. Summary of overseas data

Country	Location	Year	Rate of N kg/ha	Returns/dollar invested SCU/urea$_b$	SCU/urea$_s$	SCU/urea$_t$
India	Rajendranagar	1969	100	-1.1	–	–
	Garikapadu	1970	120	4.4	0.6	–
	Rajendranagar	1970	120	8.9	5.1	–
	Varanasi	1970	50	4.8	9.4	–
			100	-3.4	-2.4	–
	IARI	1970	50	6.2	2.8	–
			100	3.0	1.0	–
	Tjanjavur	1970	50	4.2	-1.6	–
			100	0.6	-4.0	–
	Mangalore	1970	50	3.8	1.2	–
			100	0.4	-0.4	–
	Rajendranagar	1972	125	2.4	-0.2	–
	Rajendranagar	1972	125	4.4	7.1	–
	Rajendranagar	1972	120	7.5	5.9	–
Philippines	Los Banos	1969	a	-2.7	–	–
	Dagupan City	1969	a	-1.5	–	–
	Los Banos	1971	150	1.1	-2.6	–
	Los Banos	1971	80	0.0	-0.6	–
	Los Banos	1971	80	-2.4	-4.1	–
Thailand	Ubon	1970	80	1.9	-1.6	–
	Ubon	1971	80	6.9	1.5	–
	Surin	1971	80	5.6	3.5	–
Peru	Tavara	1969–70	80	2 9	–	9.0
			160	7.4	–	8.2
			240	3.7	–	7.6
			320	3.8	–	2.8
	Bagua	1970–71	40	28.2	–	8.8
			80	13.9	–	2.9
			120	9.0	–	4.1
			160	4.5	–	0.0
			200	1.8	–	1.4
	Jequetepeque	1970–71	80	20.1	–	11.1
			160	16.8	–	15.4
			240	16.5	–	14.3
			320	7.5	–	8.3
			400	8.5	–	6.2
	Cienego (IR8)	1970–71	80	17.6	–	9.0
			160	13.0	–	4.7
			240	7.8	–	3.1
			320	2.5	–	-3.9
			400	-1.5	–	-3.6
	Vista Florida (Continuous flooding)	1970–71	80	8.8	–	-5.9
			160	6.8	–	6.1
			240	2.3	–	-3.0
			320	2.5	–	-3.2
			400	-2.5	–	-6.0

Table 22. (continued)

Country	Location	Year	Rate of N kg/ha	Returns/dollar invested SCU/urea$_b$	SCU/urea$_s$	SCU/urea$_t$
	Vista Florida (Intermittent flooding)	1970–71	80	13.7	–	7.6
			160	12.6	–	2.9
			240	3.5	–	-3.4
			320	-1.3	–	-3.2
			400	-0.2	–	-2.2

Prices used: (U.S.$)

	Rough rice/kg	Urea/kg N	SCU/kg N
India	0.07	0.30	0.41
Philippines	0.07	0.22	0.33
Thailand	0.07	0.32	0.43
Peru	0.11	0.23	0.34

[a]Yields were averaged over 25, 50, 75, and 100 kg N/ha.
b = basal dressing; s = split application; t = topdressing.

Table 23. Effect of P source and rate on yield of rough rice (kg/ha). Hyderabad,[a] India

Source	Rate of P_2O_5 kg/ha	Site 1 Crop 1 1969 wet	Site 1 Crop 2 1970 dry	Site 2 Crop 1 1970 wet	Site 2 Crop 2 1970 dry	Site 2 Crop 3 1971 wet	Site 2 Crop 4 1972 dry
Superphosphates							
TSP	30	5,035	7,400	5,088	3,724	5,787	3,563
	60	4,938	6,759	6,092	4,778	5,720	4,262
	90	5,292	6,434	6,296	4,882	5,449	3,790
	120	5,041	6,909	6,337	5,141	5,248	3,451
OSP	30	4,875	5,176	4,971	3,456	5,460	3,753
	90	5,224	6,222	6,353	5,495	5,803	4,275
Rock phosphates							
Idaho	50	4,823	5,102	3,044	3,400	5,241	3,210
	200	5,548	6,386	2,661	2,730	5,794	3,270
Florida (Central)	50	5,539	6,504	3,102	3,828	4,961	3,133
	200	5,195	5,758	3,093	3,123	5,830	2,871
Florida (North)	50	4,960	4,372	3,468	3,866	5,668	3,202
	200	5,233	6,544	2,850	3,300	5,272	3,640
North Carolina	50	4,765	5,685	3,391	2,985	5,360	3,173
	200	4,862	4,538	2,983	3,158	5,417	2,946
Tennessee	50	5,033	6,046	2,974	2,825	5,525	2,794
	200	4,694	4,565	3,970	3,780	5,803	3,735
Missouri	50	5,434	5,776	2,946	3,944	5,482	3,122
	200	4,689	4,956	3,660	3,836	5,582	3,660
Udaipur (India)	50	4,938	5,210	3,769	3,439	5,900	3,766
	200	5,094	5,356	3,062	3,205	5,575	3,305
No P	0	5,171	5,846	3,188	2,925	5,665	3,374
	LSD	N.S.	1,491	958	988	N.S.	–
	CV(%)	8.8	4.6	15.8	15.3	9.5	–

[a]Soil pH ~8.0

Table 24. Effect of P source and rate on yield of rough rice (kg/ha). India

Source	Rate of P_2O_5 kg/ha	Bhubaneswar Crop 1 1969 wet	Bhubaneswar Crop 2 1970 dry	Karamana Crop 1 1970 wet	Karamana Crop 2 1971 dry	Moncompu 1970 wet
Superphosphates						
TSP	30	2,722	2,255	5,845	4,522	5,169
	60	2,732	2,641	6,066	4,52[illegible]	5,344
	90	2,818	2,341	5,698	4,730	5,268
	120	2,540	1,947	5,625	4,849	5,597
OSP	30	2,191	2,300	5,772	4,641	5,083
	90	2,596	2,435	6,066	4,551	5,327
Rock phosphates						
Idaho	50	2,520	2,701	6,250	4,462	5,274
	200	2,818	2,367	5,735	4,492	5,026
Florida (Central)	50	2,722	2,452	6,176	4,522	5,285
	200	2,262	2,753	5,919	4,522	5,454
Florida (North)	50	2,748	2,204	6,029	4,433	5,220
	200	2,591	2,598	5,882	4,582	5,501
North Carolina	50	2,621	2,315	5,993	4,820	5,118
	200	1,984	2,538	5,735	4,582	5,130
Tennessee	50	2,606	2,367	5,846	4,552	5,788
	200	2,667	2,135	5,882	4,463	5,257
Missouri	50	2,540	2,667	5,588	4,403	–
	200	2,793	2,418	5,992	4,802	–
Udaipur (India)	50	2,570	2,873	5,735	4,641	4,921
	200	2,403	2,272	5,992	4,730	4,694
No P	0	2,424	1,869	5,845	4,492	5,071
Soil pH		5.1		5.3		5.2
	LSD	N.S.	474	N.S.	N.S.	N.S.
	CV(%)	13.5	12.6	9.1	–	7.6

Table 25. Effect of P source and rate on the yield of rough rice (mt/ha). Bulacan, The Philippines, 1970 wet season

Source	P applied (kg P_2O_5/ha) 25	50	100	200	Mean
TSP	5.6	5.6	5.4	5.6	5.6
Rock phosphates					
Idaho	5.3	5.4	5.2	5.3	5.3
North Carolina	5.4	5.6	5.3	5.4	5.4
Florida (North)	5.3	5.1	5.2	5.5	5.3
Florida (Central)	5.2	5.2	5.3	5.5	5.3
Tennessee	5.3	5.3	5.3	5.5	5.3
Missouri	5.4	5.4	5.2	5.5	5.4
Tunisia	5.1	5.4	5.7	5.6	5.5
Morocco	5.3	5.2	5.4	5.4	5.3
Control (no P)		5.2			

other was at Bangkhen Rice Experiment Station on a soil of pH 5.8. The yields for four successive crops at Klong Luang and two at Bangkhen are presented in table 26. In both cases, fresh TSP rates were applied to previously untreated plots for the second crop.

The yields from the first crop are plotted in figures 13 and 14 for Klong Luang and Bangkhen, respectively. The response to added P was quite marked at Klong Luang; a lesser degree of response was obtained at Bangkhen. The yield levels attained by TSP were highest at both locations; the more soluble rock phosphates were 79 and 56% as effective as TSP at Klong Luang and Bangkhen, respectively. These relative effectiveness values are given in table 27.

Table 26. Effect of P source and rate on the yield of rough rice (kg/ha)

Source	Rate of P_2O_5 kg/ha Crop 1	Rate of P_2O_5 kg/ha Crop 2	Klong Luang[a] Crop 1 1969 wet	Klong Luang[a] Crop 2 1970 dry	Klong Luang[a] Crop 3 1970 wet	Klong Luang[a] Crop 5 1971 wet	Bangkhen Crop 1 1969 wet	Bangkhen Crop 2 1970 dry
TSP	0	25		3,814	3,339	2,476		4,274
	0	50		3,391	2,203	1,391		4,201
	0	100		4,715	3,085	2,349		4,661
	0	200		4,712	4,379	3,171		4,590
	25		5,556	2,430	3,252	2,179	5,225	3,827
	50		5,960	2,968	2,814	1,357	5,503	4,437
	100		6,223	4,621	3,630	1,660	5,561	4,411
	200		5,866	4,723	4,714	2,966	5,797	4,695
Rock phosphates								
Idaho	25		4,417	1,977	2,837	1,481	3,658	4,284
	50		5,158	2,181	2,111	1,521	4,470	4,145
	100		5,195	3,420	3,272	2,497	4,491	4,061
	200		5,855	3,791	3,815	3,123	4,636	4,165
Florida (Central)	25		4,840	1,823	2,346	1,904	4,159	4,009
	50		5,148	2,475	3,253	2,176	4,718	3,945
	100		5,620	3,255	3,483	2,825	5,085	3,793
	200		5,644	4,243	3,522	2,997	5,313	3,989
North Carolina	25		4,989	1,641	2,806	2,038	4,608	4,043
	50		5,254	1,478	1,730	2,234	4,999	4,009
	100		5,327	3,112	1,878	2,708	5,193	4,369
	200		5,672	4,498	3,844	4,099	5,382	4,312
Florida (North)	25		5,036	2,549	2,860	2,347	4,458	4,035
	50		5,180	2,400	2,429	1,360	4,468	4,150
	100		5,881	3,548	3,901	2,955	5,128	3,782
	200		5,636	4,451	3,763	3,279	5,078	4,195
Tennessee	25		3,795	2,745	2,760	2,098	3,593	3,657
	50		4,432	2,331	2,246	1,711	3,945	3,675
	100		4,720	3,181	2,876	2,305	3,994	3,941
	200		5,098	4,062	3,141	2,358	5,105	4,284
Missouri	25		3,257	1,906	2,324	2,183	3,692	3,554
	50		2,125	934	2,110	1,718	3,651	3,850
	100		2,024	881	1,560	1,478	4,302	3,829
	200		1,910	836	794	1,282	3,900	3,837
No P	0		2,672	1,204	1,681	1,505	3,380	3,702
Soil pH				4.6			5.8	
		LSD	1,063	936	–	–	–	1,190
		CV(%)	15	24	–	–	–	28

[a]The yield of crop 4 was lost by an attack of mealy bugs.

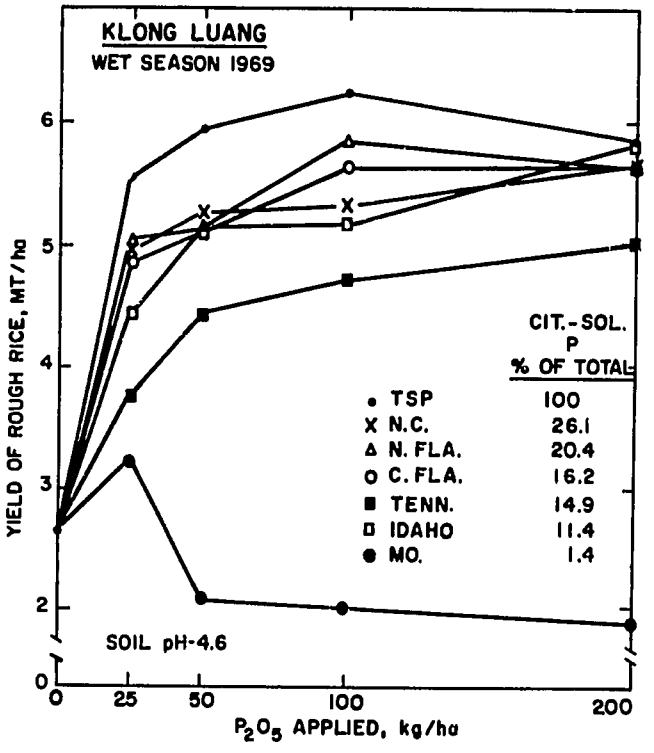


Figure 13. Effect of various phosphorus sources on the yield of rough rice

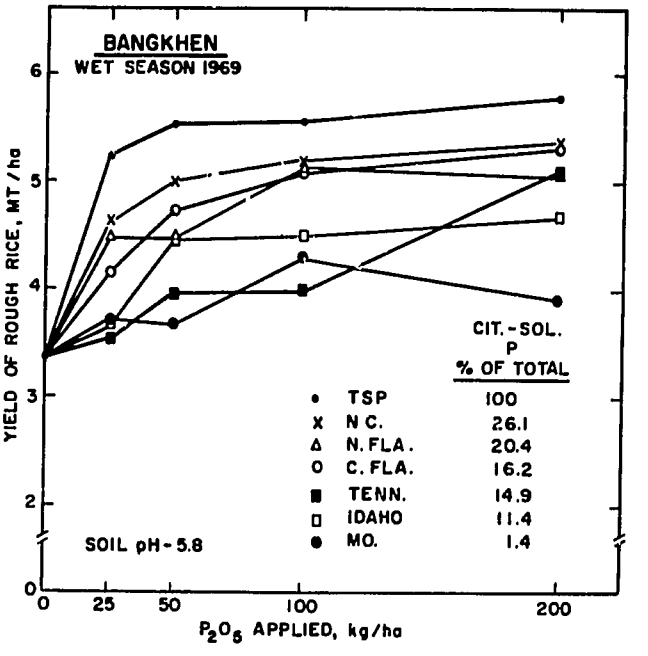


Figure 14. Effect of various phosphorus sources on the yield of rough rice

Among the rock phosphates, there was a direct relationship between citrate solubility and the response obtained. This is shown most clearly in figure 15, where relative effectiveness values are plotted against citrate soluble P as a percent of the total. Linear regression explained 92 and 88% of the variation in relative effectiveness at these two locations.

Calculations were made to determine the conditions under which TSP and rock phosphates would compete as P sources. Figure 16 shows an indifference curve which should aid in the decision-making process of choosing P sources. For example, where the price ratio of TSP:RP is 2.0 and the RAE values are 60 or greater, rock phosphate might be used. At the same price ratio, TSP should be used if the rock phosphate had an RAE value of less than 50. This curve should not be taken too literally; however, it does illustrate a method for reducing RAE of sources and relative prices to a single curve. With more refined data, such a method may become more generally useful.

Referring again to table 26, there was no measurable response to P in the second crop at Bangkhen; however, residual effects continued at Klong Luang even through the fifth crop. The residual effects of TSP were superior to those from the rock phosphates through at least the third crop; by the fifth crop, however, the more reactive of the rock phosphates showed greater residual effect than TSP.

Table 27. Relative agronomic effectiveness value[a] (RAE) for two P source experiments in Thailand. Wet season, 1969; crop 1

Source	Klong Luang	Bangkhen
North Carolina	79	56
Florida (North)	79	56
Florida (Central)	74	50
Tennessee	43	18
Idaho	52	29
Missouri	9	6
TSP	100	100

[a]Yield responses expressed as a percent of the response to TSP.

A total of 10 P sources were compared in 1970 and 1971 wet seasons at Rangsit and Kuan Gut. The initial soil pH at these locations was 4.1 and 5.0, respectively. The sources and rates employed are shown in table 28 along with the yield results obtained.

A fresh application of TSP was applied to previously untreated plots to serve as a standard for the second crop.

The RAE values for these sources are shown in table 29 for both crops. Most of the sources were similar in

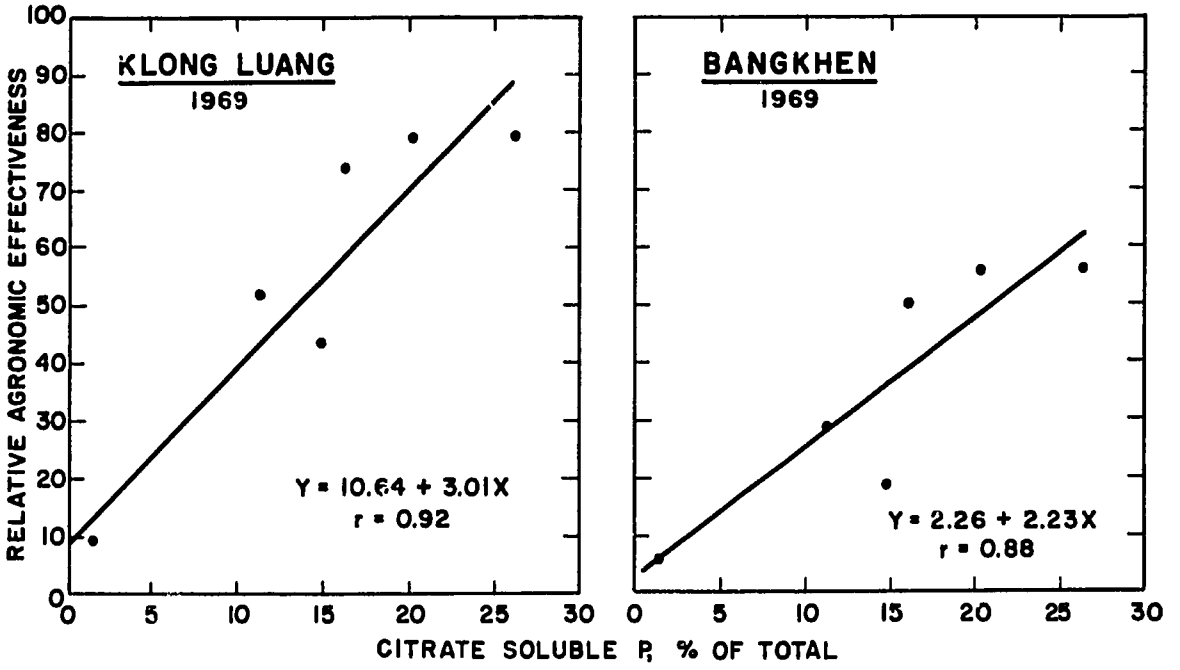


Figure 15. Relationship between relative agronomic effectiveness (RAE) and dissolution of rock phosphates in ammonium citrate

effectiveness to TSP in the first crop at Rangsit; the main exceptions were Missouri rock phosphate (almost completely ineffective) and basic slag, which appeared to be more effective than TSP. All sources applied for the first crop were substantially less effective for the second crop when compared with the effectiveness of freshly applied TSP. The source with the highest residual effect was fused Mg phosphate (RAE = 83).

All the rock phosphates were rather ineffective for the first crop at Kuan Gut. The more effective of the rock phosphates (in this case northern Florida and Tunisian rock phosphates) were still less than half as effective as TSP. Rhenenia phosphate was fairly effective, being 86% as effective as TSP. Fused Mg phosphate and basic slag were equal to or slightly more effective than TSP.

Instead of declining in relative effectiveness for the second crop as at Rangsit, the rock phosphates increased in this respect at Kuan Gut. The rock phosphates ranged from 26 to 86% as effective as freshly applied TSP. Other phosphates decreased in effectiveness about the same magnitude as at Rangsit.

There has also been some interest in granular urea-rock phosphate mixtures in Thailand. The granular forms of fertilizer are preferred for ease of application. The rationale

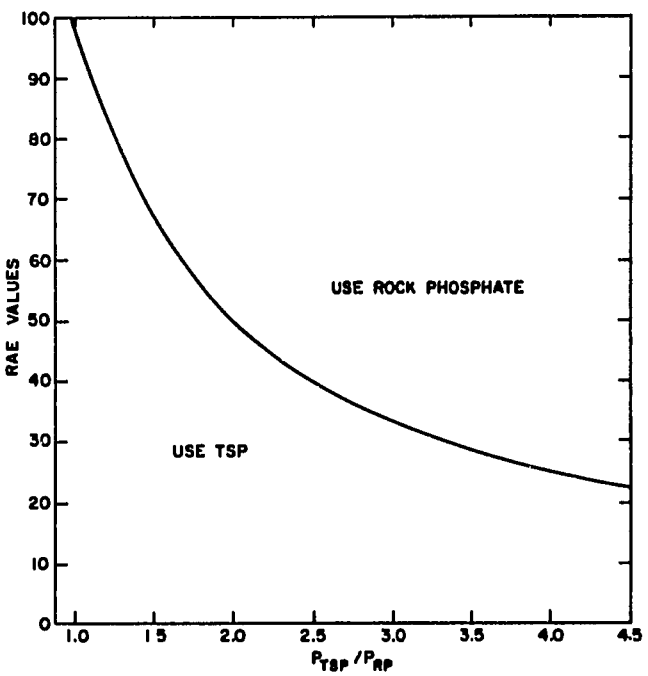


Figure 16. Relationship between RAE values and the price ratios between TSP and rock phosphate

Table 28. Effect of P source and rate on yield of rough rice (kg/ha). Thailand

Source	Rate of P_2O_5 kg/ha Crop 1	Rate of P_2O_5 kg/ha Crop 2	Rangsit Crop 1 1970 wet	Rangsit Crop 2 1971 wet	Kuan Cut Crop 1 1970 wet	Kuan Cut Crop 2 1971 wet
TSP	0	25		2,782		2,837
	0	50		2,120		3,330
	0	100		2,580		3,612
	0	200		2,854		3,353
	25		1,860	1,921	2,632	1,694
	50		2,528	1,744	2,794	2,724
	100		2,862	2,784	2,827	3,550
	200		2,360	3,013	2,932	3,268
Florida (North) RP	25		1,981	1,959	1,686	3,262
	50		2,801	1,695	2,128	2,632
	100		2,374	2,616	1,826	2,992
	200		2,955	3,055	2,101	3,487
Tennessee RP	25		1,853	1,822	1,416	1,915
	50		2,391	1,947	1,569	2,437
	100		2,694	2,212	1,918	2,932
	200		2,584	2,838	1,826	2,865
Missouri RP	25		798	1,488	1,699	1,905
	50		990	1,506	1,662	1,823
	100		994	1,760	1,446	1,432
	200		961	1,760	1,288	1,213
Moroccan RP	25		1,986	1,744	1,562	1,967
	50		2,894	1,740	1,615	2,619
	100		2,453	2,594	1,930	2,978
	200		2,859	3,185	2,292	3,289
Tunisian RP	25		1,666	1,642	1,868	2,344
	50		1,904	2,092	2,004	2,781
	100		2,744	2,379	2,002	3,199
	200		2,849	2,711	2,508	3,423
Christmas Island RP	25		1,598	1,880	1,392	1,508
	50		1,955	1,967	1,461	1,985
	100		2,746	2,274	1,564	2,505
	200		2,562	2,947	1,852	2,897
Rhenenia phosphate	25		1,846	1,779	2,318	2,056
	50		2,507	2,311	2,486	2,696
	100		2,890	2,633	2,804	3,118
	200		2,902	2,827	2,940	3,645
Fused Mg phosphate	25		2,098	2,274	2,613	1,879
	50		2,748	2,040	2,974	2,924
	100		2,821	2,728	2,863	3,765
	200		2,607	3,038	2,776	3,321
Basic slag	25		2,370	1,903	2,660	2,257
	50		3,151	1,760	2,859	2,947
	100		3,130	2,891	3,160	3,358
	200		3,322	3,122	3,040	3,607
No P	0		791	1,608	1,205	1,184
Soil pH			4.1		5.0	

for producing granular urea-rock phosphate was that urea will dissolve out quite readily, leaving a porous granule to enhance dissolution of the rock phosphate. However, this material tends to slake down quite readily since the granule is not particularly firm or durable.

The results obtained from experiments conducted in Thailand to evaluate these materials are summaried in table 30 for four locations and two successive crops. The fertilizers used and their nominal grades are shown. There is a rather basic flaw in the design of these experiments, however, there is no way to determine whether the yield response is due to added N, added P, or both.

The rather low rate of P_2O_5 (25 kg/ha) might also be questioned, particularly for granular rock phosphates.

The relative effectiveness values for these various sources are presented in table 31. There is a good deal of variability in effectiveness among these locations and crops within locations. Ordinarily, one would assume in such cases that variation in effectiveness would occur as a result of differences in the effectiveness among the P components. However, the variability seems to be quite random and not related to known characteristics of the fertilizers. Perhaps it is safe to say that these fertilizers seem generally similar in effectiveness to urea plus TSP except at Kuan Gut. There is some question regarding the value of the nitrate in ammonium phosphate nitrate; this form of N is not very effective in flooded soils.

Table 29. Relative agronomic effectiveness values for two P source experiments in Thailand. Wet seasons, 1970 and 1971

	Rangsit		Kuan Gut	
Sources	Crop 1	Crop 2	Crop 1	Crop 2
North Florida RP	98	54	44	86
Tennessee RP	94	44	28	60
Missouri RP	8	0	26	26
Moroccan RP	102	47	32	64
Tunisian RP	81	48	49	77
Christmas Island RP	80	49	17	39
Rhenenia phosphate	100	71	86	69
Fused Mg phosphate	108	83	104	81
Basic slag	129	65	109	80
TSP	100	61	100	71
TSP (fresh)		100		100

Ceylon—Two experiments were conducted during the 1969-70 season. The sources and rates employed are indicated in table 32 along with the results obtained. There was a significant response to added P at Gampola, none at Maha Illuppallama. There were no significant differences among P sources.

Colombia—An experiment comparing various P sources was conducted at Carimagua in the Llanos Orientales, the plains east of The Andes mountains. The soils are highly weathered and are considered typical oxysols. The soil at Carimagua is considered very low in available P and is quite acid (pH 4.3). The sources used and the results obtained are shown in figure 17. The yields are rather low as a result either of "oranging" disease or blast.

The yields indicate that the North Carolina rock phosphate may have been more effective than TSP, at least at the higher rates of application. The Idaho rock phosphate approached TSP in effectiveness at the highest rate. The Colombian source, Boyaca, was quite ineffective because of coarse particle size and/or low solubility.

Table 30. The effect of various granular N-P fertilizers on the yield of rough rice (kg/ha)[a]

	Nominal	Petchburi		Sakolnakorn		Kuan Gut		Rangsit	
Fertilizer	grade	1970	1971	1970	1971	1970	1971	1970	1971
Urea–RP	26-13-0	5,260	3,267	1,977	1,718	1,204	2,917	1,512	1,160
Urea–RP	18-18-0	5,050	3,371	1,712	1,866	1,185	2,685	1,523	926
Ammonium phosphate	16-20-0	5,284	3,294	2,060	1,449	1,664	3,500	1,393	959
Ammonium phosphate nitrate	20-20-0	4,797	3,050	2,010	1,865	1,530	3,234	1,576	931
Urea + TSP	–	5,200	3,347	2,026	1,694	1,607	3,412	1,304	1,120
Control– N_0P_0		3,919	1,514	1,152	1,133	801	1,323	370	364
Soil pH		7.1		4.6		5.0		4.1	

[a]Data are averaged over three application times:
a. N-P application at transplanting.
b. N-P application at 3 weeks after transplanting.
c. N application at panicle initiation.

Table 31. Relative effectiveness values for various granular N-P fertilizers at several locations in Thailand

Fertilizer	Nominal grade	Petchburi		Sakolnakorn		Kuan Gut		Rangsit	
		1970	1971	1970	1971	1970	1971	1970	1971
Urea–RP	26-13-0	105	96	94	104	50	76	122	105
Urea–RP	18-18-0	88	101	64	131	48	65	123	74
Ammonium phosphate	16-20-0	107	97	104	56	107	104	110	79
Ammonium phosphate nitrate	20-20-0	69	83	98	130	90	91	129	75
Urea + TSP	–	100	100	100	100	100	100	100	100

Table 32. Effect of P sources and rate on yield of rough rice (kg/ha). Ceylon, 1969-70

Source	Rate of P_2O_5 kg/ha	Locations: Gampola (wet zone)	Locations: Maha Illuppallama (dry zone)
TSP	25	4,100	5,732
	50	4,953	5,883
	100	5,432	6,394
	200	5,648	6,205
Rock phosphates			
Idaho	25	4,171	5,202
	50	4,816	5,732
	100	5,435	6,091
	200	5,538	6,583
Florida (Central)	25	4,558	6,848
	50	4,280	5,751
	100	5,157	6,242
	200	5,513	6,186
North Carolina	25	4,646	5,997
	50	5,022	6,091
	100	5,325	6,148
	200	5,408	6,091
Florida (North)	25	4,498	5,997
	50	4,340	5,448
	100	5,052	6,488
	200	5,524	6,640
Missouri	25	4,120	6,224
	50	4,930	6,299
	100	5,040	5,864
	200	5,209	6,432
Control (no P)		4,050	5,893
	LSD	747	1,053

Interpretation of Data on P Sources

The interest in the less soluble P sources for the more acid soils seems to be well placed, not only for rice but also for the upland crops. It appears that certain rock phosphates can represent alternatives to the more costly acidulated phosphates. As a rather crude estimation, it appears that the price per unit of P in the acidulated phosphates should be near twice that in the rock phosphate before the latter should be considered seriously as an alternative. The rock phosphate chosen should contain "some" citrate soluble P in order to be effective. The evidence on what the minimum level should be is quite meager; however, it would appear that the content of citrate soluble P should be no lower than 15% of the total P contained in the rock phosphate.

It should also be pointed out that only rarely have the rock phosphates equalled TSP in maximum yield. Generally the more reactive rocks are slightly less effective.

An attempt has been made to estimate the portion of the rice-growing area in selected countries in Southeast Asia that is sufficiently acid to be suitable for rock phosphate application (table 33). After omitting the very acid soils of less than pH 4.0, there still appears to be substantial areas suitable for rock phosphate application. The estimate is 62% of the rice-growing area of Malaysia, 78% of the rice-growing area of Thailand, and 32% of the rice-growing area of South Vietnam.

There is some interest in granulating urea and rock phosphate for convenience in handling and application. The evidence is conflicting at this point as to the agronomic effectiveness of these products. *A priori*, it would be expected that the effectiveness of most rock phosphates would be reduced when granulated; this is a consequence not only of reduced distribution in the soil but also of reduction of surface area for dissolution. Results of TVA greenhouse experiments with both flooded rice and upland crops tend to bear out this reasoning (see figure 18). However, results available from experiments in Thailand appear to be in conflict with the above; i.e., these granulated urea-rock phosphates appeared to be quite satisfactory fertilizers at three out of four locations. Because of choice of experimental design, it is not possible to determine whether a response to P occurred at these locations.

As alternatives to the rock phosphates and the water-soluble phosphates, attention should be directed also toward the water-insoluble, citrate-soluble sources. Thailand experiments indicate that basic slag and fused magnesium phosphate were equal to or more effective than TSP. It is possible that these sources will offer real potential in terms of agronomic effectiveness on acid soils.

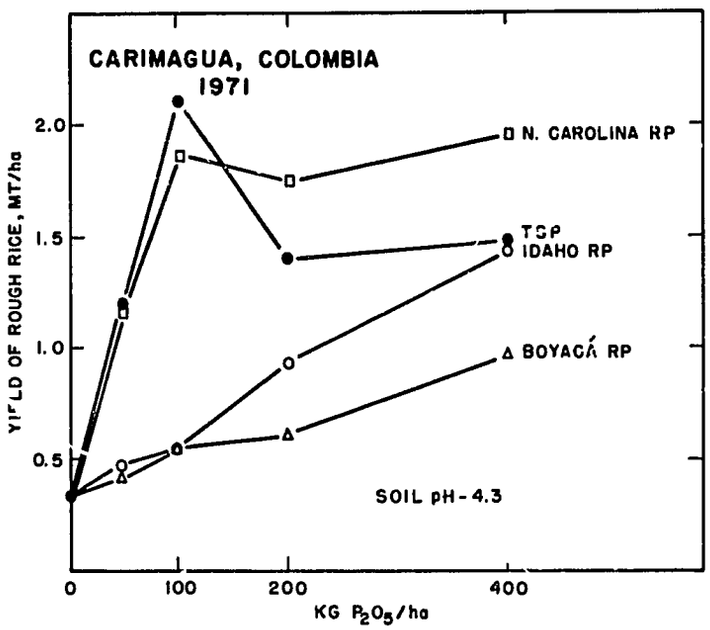


Figure 17. The effect of P source and rate on the yield of rough rice

Table 33. Proportion of rice-growing areas in selected southeast Asian countries that may be suitable for rock phosphate application

	Area in flooded rice	Area of alluvial soils: Acid (> pH 4.0)	Area of alluvial soils: Very acid (< pH 4.0)	Area of acid terrace soils (> pH 4.0)	% of rice area[a]
		1,000 hectares			
Malaysia	480	250	25	50	62
Thailand	6,800	2,000	685	3,300	78
South Vietnam	2,500	800	618	–	32

[a]Including only the acid alluvial and acid terrace soils. The very acid alluvial soils (acid sulfate soils for the most part) are not included in this percentage calculation.

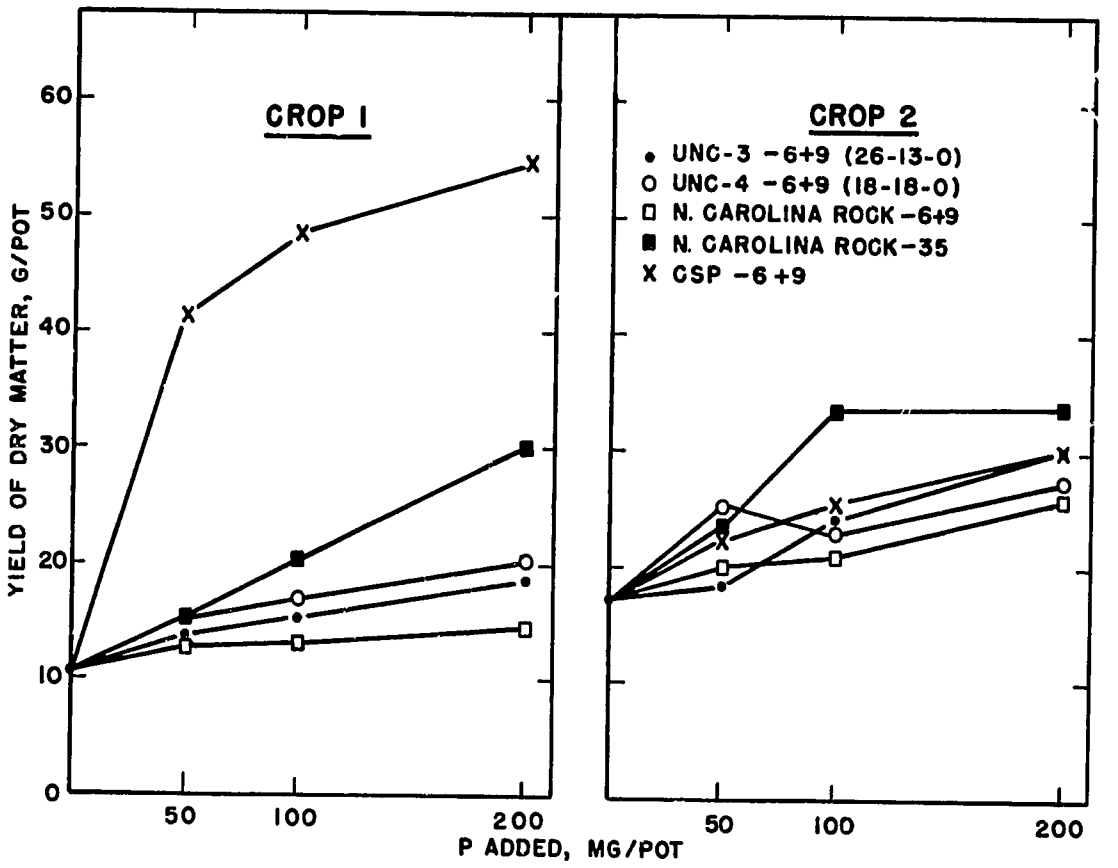


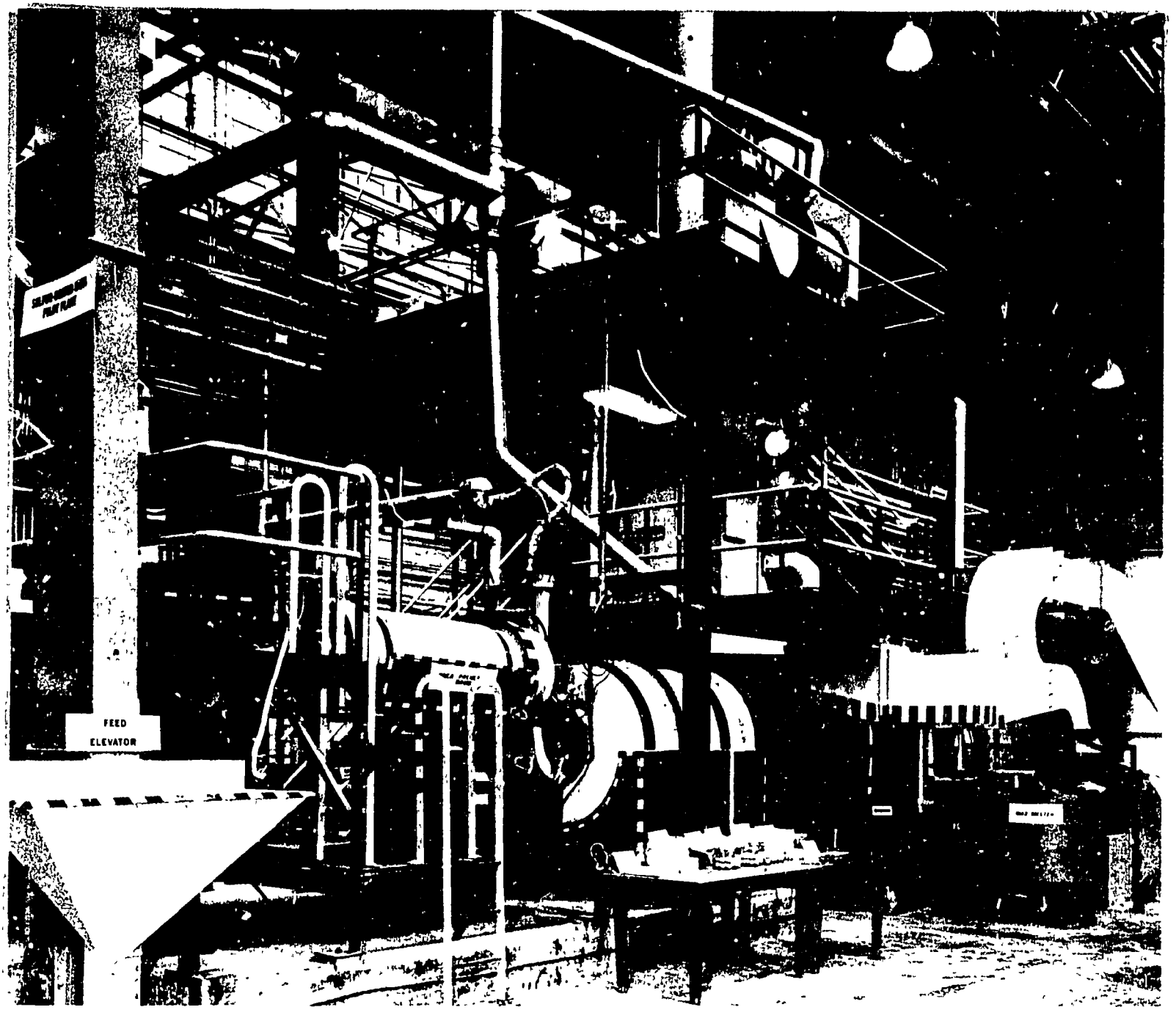
Figure 18. The effect of granulation of North Carolina rock phosphate with and without urea on yield of dry matter in a TVA greenhouse experiment

Fertilizers Tested

Throughout the course of this work, approximately 30 different fertilizer materials have been used in greenhouse and field experiments. Much emphasis, however, was given to SCU, rock phosphates, and zinc sources. These and other materials are described below.

SULFUR-COATED UREA

SCU is the culmination of 15 years' work on development of a controlled-release nitrogen fertilizer. During this



Sulfur-coated urea pilot plant at TVA National Fertilizer Development Center.

period, numerous compounds and coated products were screened. For numerous reasons, SCU is the only nitrogen fertilizer developed thus far that offers potential where the controlled-release feature is needed The development of SCU is based on the idea of a nitrogen fertilizer that would release its nitrogen in the necessary amounts and at the proper time required by growing plants. Thus the roots could take up nitrogen as needed with only minimal losses due to volatilization and leaching. It is possible to achieve such a release pattern through coating to vary water solubility of the nutrient or by varying the particle size of slowly soluble chemical compounds. TVA in the early 1960's began a search for an economical coating agent to obtain a controlled-release nitrogen fertilizer.

SCU consists of a urea substrate (granules) coated with a layer of sulfur. The sulfur forms the basic coating medium, but due to its physical characteristics some cracks and uneven coatings are obtained. A wax sealant is applied over the sulfur along with a microbicide (to resist attack by soil micro-organisms). The "tackiness" of the wax coating is overcome by a final coating of conditioner Therefore, a multilayered product is obtained. Coatings consisting of sulfur only have been developed recently but agronomic data on such products have not been obtained. The nitrogen

content of unconditioned urea is 46% but the urea used in most of the pilot plant work had been conditioned by the manufacturer with about 1% diatomaceous earth to prevent caking, reducing the nitrogen content to about 45%. Coated products contained 34 to 40% N.

A relatively simple procedure was developed in the laboratory to evaluate the coating effectiveness. Samples are immersed in water at 38° C (100° F) for 7 days to determine the quantity of urea dissolved. Typical coatings and dissolution rates are shown in table 34. It is impossible to apply the same coating thickness to each individual particle. Therefore, the product actually consists of a mixture of coated granules each having its own specific dissolution rate. The dissolution rate is then an average based on the range of dissolution rates. The median rate can be increased or decreased by varying the average coating thickness.

After the initial 7-day period, the dissolution rate in water at 38° C declines and usually is 1% or less per day. The rate depends on the temperature and on the quality and thickness of the coating. Dissolution rates in soils depend on numerous factors and are not necessarily the same as in water.

Numerous other coatings, such as urea-formaldehyde resins, paraffin-type waxes, petrolatum-rosin-paraffin, and phenol-formaldehyde, have been used as a coating medium for controlled release. Although some of the materials appear promising as a conditioning agent, none compared favorably with the coating quality of sulfur. Sulfur is, of course, a relatively inexpensive material and after degradation in the soil is a plant nutrient.

Production Technology and Status

At the present time, SCU is being produced in an experimental pilot plant with a capacity up to 0.9 mt/hr or 1 st/hr. Throughout the period of development, the process has progressed from laboratory scale (small batch unit), to a 136 kg/hr [300 pounds per hour (lb/hr)] continuous pilot plant, to the present scale. The ongoing test program is providing data required for further scale-up. Much of the product used in the agronomic test program was produced in the 0.9 mt/hr plant. Some limited tests have been carried out up to 1.8 mt/hr in the pilot plant.

A flow diagram for the SCU process is shown in figure 19. Granular urea is preheated and fed to a rotary drum where molten sulfur is sprayed onto the moving bed of particles. The product then goes to a second rotary drum where a mixture of wax and coal tar is added by spraying. After discharge from the second drum, the sulfur-wax coated product is cooled and then dusted with a fine-ground powder to overcome the tackiness of the wax. The material can be sold in bag or bulk form. A typical product would contain about 39% nitrogen. It should be pointed out that products have also been made using sulfur only which may be satisfactory for some cropping situations.

The use of a granular urea is recommended over air-prilled urea as larger urea particles are easier to coat and require less sulfur to obtain a given controlled dissolution rate. TVA has developed a method for granulation of urea in a pan-type granulator. This product is significantly less fragile than air-prilled urea.

Estimated Production Cost

Based on a preliminary estimate for a 454 mt/day (500 st/day) plant, the estimated coating cost, including 15% return on investment is $16.79/mt as shown in table 35. For comparison, if urea were $58/mt, 1 mt of coated product would be about $66 or approximately 30% more on a nitrogen basis. Transportation and handling costs would be about 15% higher on a nitrogen basis due to the lower nitrogen content (39 vs 45%). Even with the lower nitrogen content, the material is still more concentrated than the other commercially available nitrogen materials such as ammonium nitrate (33.5% N) or ammonium sulfate (21% N).

Other Product Characteristics

Although SCU was developed primarily as a controlled-release nitrogen fertilizer, certain other advantages have been identified which should greatly enhance its utilization.

Table 34. Composition and dissolution rate of urea and SCU

Product	coating wt., % (total)	Product composition % N	% S	Dissolution Rate in 7 days @ 38 C
Urea	0	46 (45)[a]	0	100
SCU[b]	14	40	9	25
SCU[b]	18	38	13	15
SCU[b]	21	36	16	9
SCU[c]	18	38	18	30
SCU[c]	24	35	24	15

[a]Material actually used contained 45% N as it was preconditioned with clay (1%) prior to sulfur coating.
[b]Contains 1% clay preconditioner, 2% wax, 0.2% coal tar, and 2.0% final conditioner.
[c]Coating consists of sulfur only.

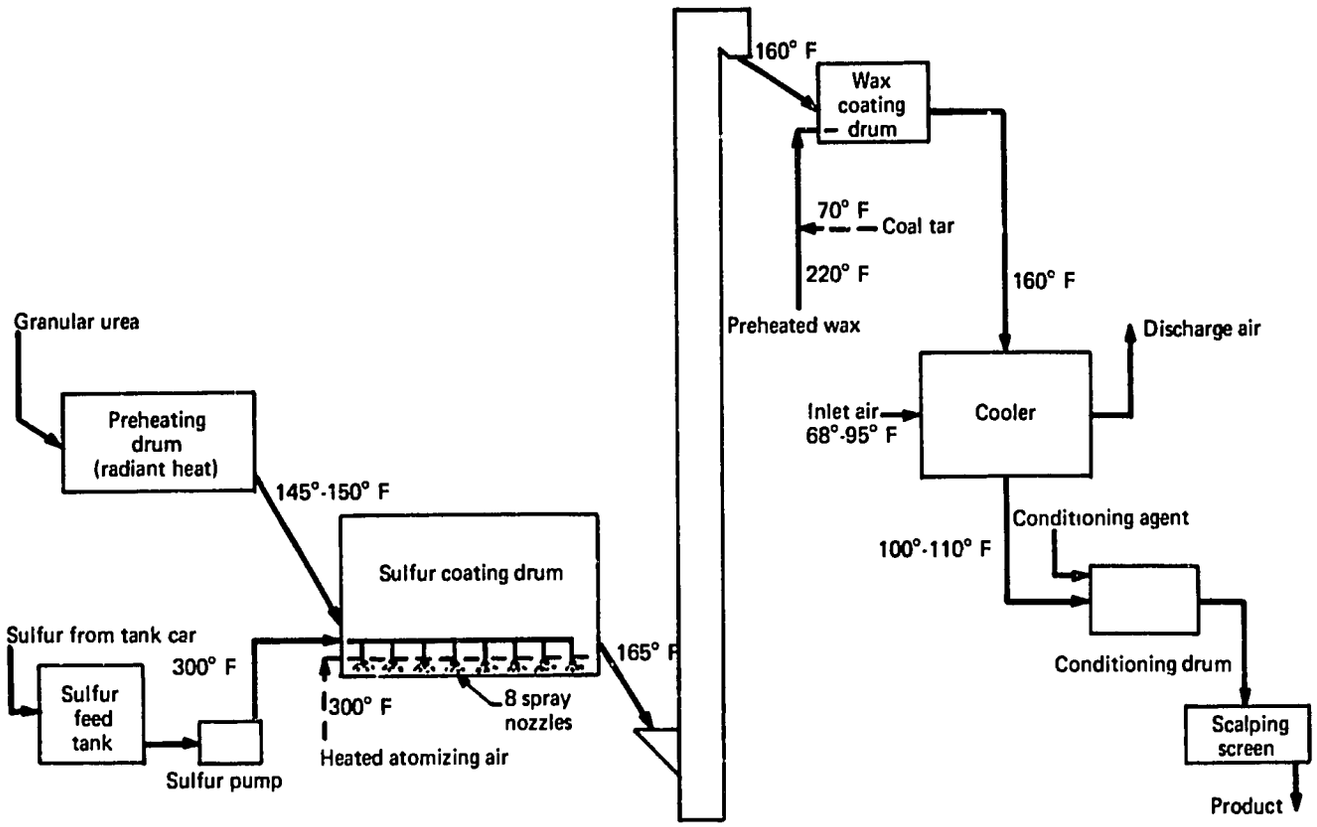


Figure 19. Flowsheet of pilot plant for sulfur coating of urea

Table 35. Estimated coating cost plus return on investment for a commercial plant for SCU

Plant Capacity: 453.5 mt/day or 150,000 mt/year (330 days)
500.0 st/day or 165,000 st/year
Total capital investment: $2,700,000
Product grade: 39-0-0-10S

Raw materials	Tons/ton of product	Cost, $/mt	$/mt of product
Sulfur	0.10	30	3.00
Wax	0.02	129	2.58
Microbicide	0.0025	103	0.26
Conditioner	0.02	55	1.10
			6.94
Operating costs			7.15
Total			14.09
Return on capital investment (15% ROI)			2.70
Coating cost plus ROI			16.79

Coating cost plus ROI, $/mt of N = 43.
Coating cost plus ROI, $/20-lb unit of N = 0.39.

Improved Hardness--Sulfur-coated granular urea is about twice as hard to crush as air-prilled urea and consequently less dusting and breakage during handling and transport is experienced.

Compatibility with Superphosphate--SCU can be blended with unammoniated granular TSP, whereas uncoated urea cannot. Less segregation occurs as the sulfur-coated granules are larger than air-prilled urea.

Better Storage Properties in Humid Areas--The coating on urea eliminates the tendency to cake, even in high-humidity areas. The product is easier to handle, especially in developing countries where handling and storage equipment is often inferior.

Future Work

TVA intends to continue development and improvement in the process for SCU through the engineering and agronomic test program. Refinements in equipment and procedure are constantly being made. Plans are being made to further scale-up the process to obtain more reliable engineering and economic data. Larger quantities of material will enable agronomic tests to be extended to other areas and to other crops.

ROCK-PHOSPHATE BASED MATERIALS

The trend in developed countries is toward utilization of phosphate rock in chemical processes to produce high-analysis fertilizer intermediates and products. Phosphate rock is reacted with mineral acids, including sulfuric, phosphoric, and nitric acids, and a variety of materials ranging from single superphosphate (20% P_2O_5) to diammonium phosphate (18% N, 46% P_2O_5) is produced. Economics usually favor the shipment of high analysis intermediates and products It is the contention of some researchers, however, that certain selected rock phosphates may be efficiently and economically utilized directly for rice fertilization in some areas of the world. TVA has been investigating this possibility as part of this overall project.

Phosphate rocks have been evaluated in laboratory and field programs for direct application for a number of years. The subject has been a source of controversy as results vary widely. Work by Lehr and McClellan of TVA has been aimed primarily at characterizing a number of commercially available rocks and attempting to unravel the reasons for various types of rock behavior. Laboratory procedures are being developed which improve the prediction of agronomic effectiveness of rocks.

Potential for Direct Application of Rock

It is necessary to define the limits that may allow phosphate rock to be utilized for direct application for rice fertilization. Rocks that have good potential are those that have a high degree of carbonate substitution; that is, the carbonate ion replaces part of the phosphate ion in the crystal lattice. This is not to be confused with free calcium carbonate that is often associated with phosphate rocks. These substituted rocks can be utilized on acid soils in the pH range of 4 to 5.5 which is the case in many developing countries. The rocks must be finely ground. Rocks which are essentially fluorapatite $[Ca_{10}(PO_4)_6F_2]$ are not expected to be useful for direct application. Agronomic tests were conducted and results are given in this report for a series of rock phosphates having a wide range of carbonate substitution in the apatite component to compare the relative phosphorus availability.

Rock Series Tested for Direct Application

TVA selected six U.S. rocks and one from India described below for the test program. Sufficient quantities were obtained and properly sized for distribution to cooperators. The chemical composition is shown in table 36 and the phosphate and screen analysis data are given in table 37.

This series was selected to give a wide range of citrate solubility (1.4 to 26.1% of total P_2O_5) and carbonate substitution. Accessory minerals in the rocks were primarily quartz, calcitic and dolomitic carbonates, illite clay, hydrous iron oxide, and assorted heavy minerals. The sample of igneous apatite (MO., MR-505) contained muscovite in place of clay, ilmenite ($FeTiO_3$) in place of simple hydrous iron oxides, and fluorite (CaF_2) in addition to the quartz, calcite, and heavy minerals. Collectively, the types of accessory minerals common to these phosphate rocks should have no effect on their behavior as phosphate fertilizers. For further information on these and other rocks studies by TVA, Bulletin Y-43, "A Revised Laboratory Reactivity Scale for Evaluating Phosphate Rocks for Direct Application" is available.

Rock Particle Size for Direct Application

It has been demonstrated in numerous greenhouse and field experiments that rock phosphates for direct application should be available to the plant in finely ground form. Although an exact specification has not been determined, it appears that 75% of the sample should pass a 200-mesh (Tyler) screen. Finely ground material in this size

Table 36. Gross chemical composition of phosphate rocks tested for direct application[a]

TVA No. Rock source	MR-505 Missouri[b] (MO.)	MR-469 India[c] (UDAIPUR)	MR-468 Tennessee (TENN.)	MR-465 Idaho (IDAHO)	MR-464 Central Florida (C. FLA.)	MR-466 North Florida (N. FLA.)	MR-467 North Carolina (N.C.)
Constituent				Composition, weight %			
CaO	50.1	54.2	42.3	46.8	47.5	48.3	48.6
P_2O_5	34.7	40.1	30.1	32.3	32.7	32.4	29.9
F	3.4	3.6	3.2	3.2	3.6	3.7	3.5
CO_2	2.8	0.7	1.4	2.4	3.3	4.0	5.4
Na_2O	0.27	0.11	0.40	0.96	0.66	0.68	0.99
K_2O	0.16	0.02	0.65	0.36	0.15	0.21	0.13
MgO	0.63	0.04	0.28	0.37	0.32	0.46	0.55
Al_2O_3	0.34	0.30	1.40	1.10	1.20	0.75	0.46
Fe_2O_3	2.60	0.40	1.20	0.44	1.45	0.73	0.68
SiO_2	2.8	1.2	10.0	5.4	5.2	2.8	1.6
Total S	0.08	0.01	0.2	0.9	0.4	0.4	1.1
Sulfide-S	nil	nil	0.006	0.008	0.005	0.005	0.08
Ignition loss at 1100°C	2.6	0.9	5.3	6.9	6.8	8.0	11.1

[a]Samples dried at 105°C to obtain compositions on a moisture-free basis.
[b]Byproduct concentrate.
[c]Jhamar-Kotra district, Udaipur; high-grade material from block-D zone through Hindustan Zinc Company.

Table 37. P_2O_5 analysis and particle size of phosphate rocks tested for direct application

TVA No.	Rock source[f]	CO_3 PO_4 mole ratio[a]	Total P_2O_5	Citrate-sol. P_2O_5[b]	Citrate-sol. % of total	Screen analysis[c] (Tyler), % +65	-65 +100	-100 +150	-150 +200	-200 +325	-325
MR-505	Missouri[d] (MO.)	0.008	34.7	0.5	1.4	0.0	2.0	10.5	30.0	33.5	24.0
MR-469	India[e]	0.028	40.1	2.1	5.2	5.2	5.5	4.7	5.3	5.5	73.8
MR-468	Tennessee (TENN.)	0.079	30.1	4.5	14.9	12.0	10.5	9.0	12.5	12.5	43.5
MR-465	Idaho (IDAHO)	0.089	32.3	3.7	11.5	–	0.3	0.5	3.5	15.5	80.2
MR-464	Central Florida (C. FLA.)	0.164	32.7	5.3	16.2	–	4.2	7.8	20.2	16.8	51.0
MR-466	North Florida (N. FLA.)	0.184	32.4	6.6	20.4	15.8	8.7	6.8	9.5	10.5	48.7
MR-467	North Carolina (N.C.)	0.266	29.9	7.8	26.1	–	2.0	3.2	6.0	9.8	79.0

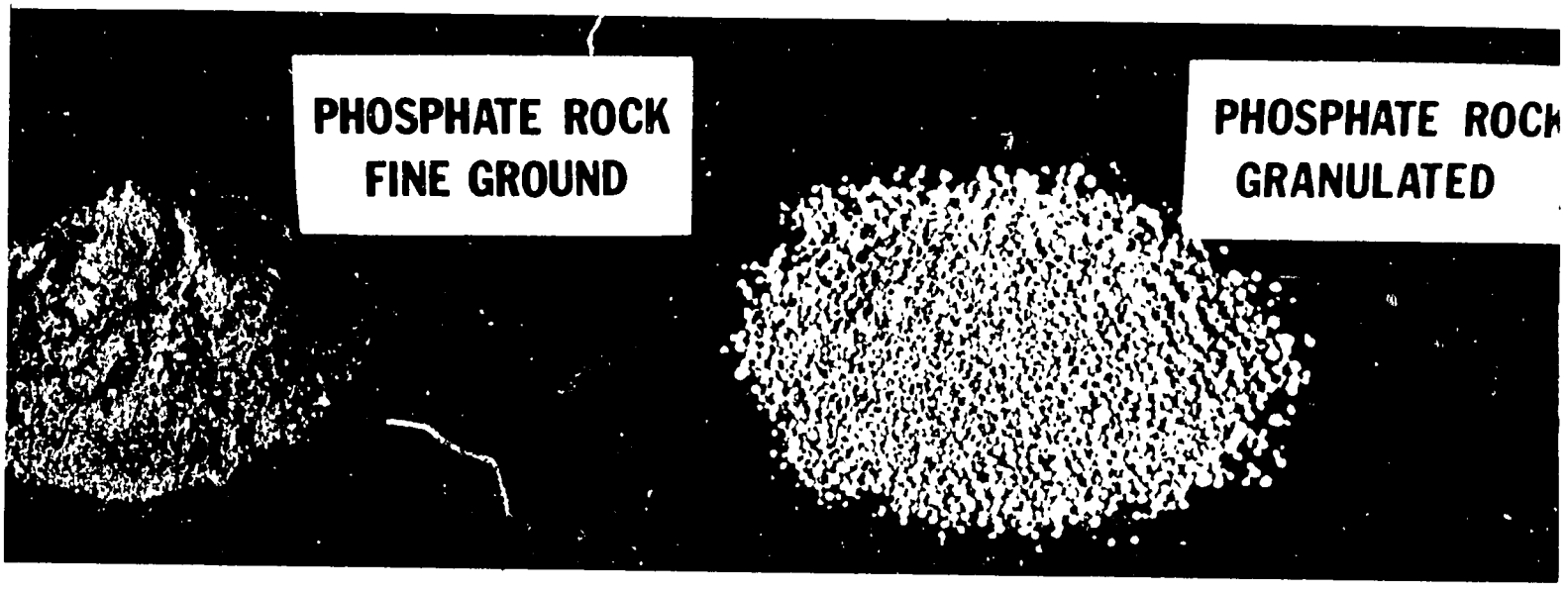
[a]Determined by chemical analysis
[b]Neutral ammonium citrate (AOAC) method.
[c]Rocks ground at TVA.
[d]Byproduct concentrate.
[e]Jhamar-Kotra district, Udaipur; high-grade material from block-D zone through Hindustan Zinc Company.
[f]The phosphate rocks listed are presumed to be typical of material from their geographic source; however, considerable variation in grade and reactivity may occur in different rocks from the same general area.

range is dusty and difficult to transport, store, and apply. Methods are being studied for granulating finely ground rock to eliminate some of these undesirable features.

Granulated Materials Based on Finely Ground Rock Phosphate

Finely ground rock phosphates are being used in some locations for direct application. Generally, the rock is ground and bagged near the point of use. However, farmers prefer to handle and apply granulated materials. TVA is studying ways of granulating finely ground rock with the objective of eliminating handling and application problems.

Rock Phosphate Granules--Tests for production of this material were made with laboratory and pilot-plant equipment. Sulfuric acid was used as a granulating agent and to react with a portion of the rock to provide some water-soluble phosphate. Some water-soluble phosphate should be helpful for the early stages of plant growth.



Comparison of finely ground and granulated phosphate rock.

Sulfuric acid (20 to 33% H_2SO_4) was sprayed onto a moving bed of fine-ground rock in a pan granulator. The quantity of acid was limited to about 25% of that required to make single superphosphate. Two types of rocks were used: uncalcined North Carolina (20.9% P_2O_5; 89% -200 mesh) and uncalcined central Florida (32.7% P_2O_5; 68% -100 mesh). A direct flame was applied to the rolling bed to aid in granulation. After cooling of the product, it was sized by screening to -5+14 mesh (Tyler). The product granules were not as strong as desired and further tests are planned. Product made from North Carolina rock contained 26% total P_2O_5 of which 10.6% was soluble in neutral ammonium citrate and 5.3% soluble in water; the equvalent values from central Florida rock were 28.1% total, 10.4% citrate soluble, and 6.1% water soluble.

These products are being compared with finely ground rock in agronomic tests.

Urea-Phosphate Rock Granules—Granulated urea-phosphate rock is a homogenous mixture of urea and fine-ground phosphate rock. Urea provides the granulating medium for binding together the small rock particles. It is expected that in the presence of moisture, the granules will rapidly disintegrate to provide small rock particles for plant growth.

Best products have been made in a pan granulator (compared with a rotary drum) by spraying a hot concentrated urea solution (99% urea) onto a moving bed of solids. After cooling, product is screened, conditioned, and bagged. Product size was -6+16 mesh. Grades of 26-13-0 and 18-18-0 have been made.

PREPARATION OF MICRONUTRIENT SOURCES

Fertilizer materials containing micronutrients were produced either by blending and coating materials purchased from commercial plants and the TVA pilot plant or from the TVA demonstration plants. Base granular fertilizers were ammonium orthophosphate, ammonium polyphosphate, ammonium phosphate nitrate (30-10-0), ammonium sulfate, superphosphates (0-52-0 and 0-46-0), urea, urea-ammonium phosphate, and nitric phosphate (20-20-0 and 26-13-0). The micronutrients and secondary nutrients used and their sources are as follows:

Micronutrient	Source
Boron	$Na_2B_4O_7$
Cobalt	$CoSO_4$
Copper	Cu_2O
Iron	Fe-EDTA
Magnesium	$K_2SO_4 \cdot 2MgSO_4$
Molybdenum	Na_2MoO_4
Sulfur	S (elemental), K_2SO_4
Zinc	$ZnSO_4$, ZnO

In coating the powdered micronutrients onto the granular carrier fertilizers, liquid binders in the amounts of 0.5 to 5.2% of the total mixture were used to make the powder adhere to the granules. This was done in a mixer which imparted a rolling action to the bed of fertilizer granules. An ammonium polyphosphate liquid fertilizer base solution (11-37-0) was used as the binder for coating

Table 38. Examples of materials containing micronutrients for agronomic tests

Code No.	Base for N of P_2O_5 carrier[a]	Micronutrient[b]	Plant food ratio	Analysis, wt, % Total N	Total P_2O_5	K_2O
P71CB-5	Blend of APP, NPB, $K_2SO_4 \cdot 2MgSO_4$	Mg, S	3:2:3	11.6	7.6	11.6
P71Fe-1	Coated APP	Fe	1:4:0	12.0	49.3	0
P71MM-1	Blend of TSP, KCl	Co, Cu, Mo, S, Zn	0:1:2	0	16.8	33.6
P71Zn-2	Coated AS	Zn	1:0:0	20.2	0	0
P71Zn-3	Coated U	Zn	1:0:0	38.0	0	0

[a]APP = granular ammonium polyphosphate; NPB = nitric phosphate (26-13-0); $K_2SO_4 \cdot 2MgSO_4$; TSP = granular triple superphosphate; KCl = potassium chloride; AS = granular ammonium sulfate; u = urea.
[b]Micronutrients added in various quantities to make a variety of products

Table 39. Materials used in agronomic tests for fertilization of rice

Material	Symbol or identification	N	P_2O_5	Remarks
1. Urea	Urea	45 or 46	0	Used as air prills or granules
2. Urea and sulfur	Urea + S	-	–	Urea mixed with finely divided sulfur
3. Urea and nitrification inhibitors	Urea + AM	–	–	Urea + 2-amino-4-chloro-6-methyl pyrimidine
	Urea + N-serve	–	–	Urea + 2-chloro-6-(trichloro-methyl pyridine
	Urea + ST	–	–	Urea + 2 sulfanilamidothiazole
	Urea + Cl 1580	–	–	2, 4-diamino-6-trichloromethyl triazine
4. Shellac-coated urea	–	–	–	Urea coated with shellac (Indian product)
5. Ammonium sulfate	AS	20-21	0	Crystalline form
6. Isobutylidene diurea	IBDU	30-31	–	Urea reacted with isobutyraldehyde
7. Crotonylidene diurea[d]	CDU	31	–	Urea reacted with crotonaldehyde
8. Ammonium nitrate sulfate	–	30	0	Mixture of nitric & sulfuric acids reacted with ammonia
9. Calcium ammonium nitrate	–	21	0	Mixture of ammonium nitrate and limestone
10. Triple superphosphate	TSP	0	46	Phosphate rock reacted with phosphoric acid
11. Ordinary superphosphate	OSP	0	20	Phosphate rock reacted with sulfuric acid
12. Tunisia–rock phosphate	–	0	29	Ground rock[a]
13. Morocco–rock phosphate	–	0	32	Ground rock
14. Rhenenia–phosphate	–	0	25[c]	Phosphate rock calcined with sodium salts
15. Christmas Island–C-grade phosphate	–	0	30[c]	Calcined high-alumina ore[b]
16. Fused magnesium phosphate	–	0	20[c]	Phosphate rock fused with magnesium silicate
17. Basic slag	–	0	17[c]	A byproduct of the steel industry
18. Ammonium phosphate (ortho)	DAP	18	46	Ammoniated phosphoric acid
19. Ammonium phosphate nitrate	APN	30	10	Nitric and phosphoric acids reacted with ammonia
20. Sulfur-coated urea + urea	SCU-urea (½-½)	42	–	Blend of urea with sulfur-coated urea

[a]Tunisian rock phosphate used for direct application is mined at Gafsa where the most reactive rock is found. Tunisian rock from other mines may be less reactive.
[b]Trade name "calciphos."
[c]Typical values.
[d]CDU made in Japan is produced from acetaldehyde and urea and is called "cyclodiurea." The same product is made in Germany from crotonaldehyde and urea.

micronutrients onto granular ammonium polyphosphate. Sixty percent aqueous base solutions of ammonium orthophosphate, ammonium phosphate nitrate, ammonium sulfate, and urea were used when coating micronutrients onto the respective granular carrier fertilizers. For coating onto superphosphates, a mixture of 40% soft wax and 60% diesel oil was used as the binder. A conditioner of 2.0% diatomaceous earth was used on products made with liquid-fertilizer binder, but no conditioner was used with the oil-wax type binder. Some examples of materials made are given in table 38. A wide variety of products are kept in inventory and are available to researchers on rice fertilization as needed.

Other Materials

A summary of additional materials used in the agronomic tests for rice fertilization is given in table 39. Some of these materials such as urea plus sulfur and ammonium phosphate nitrate were made at TVA, while materials such as IBDU and TSP were purchased through commercial sources.

Recommendations for Further Work

In a study such as reported herein, numerous questions can be asked at the conclusion of the project. Have the objectives really been met? Have we really improved the efficiency of rice fertilization? In all fairness, the development of SCU is not the ultimate answer, but represents the best compromise based on technological and economic considerations at this time. TVA feels that further improvements in this material can and should be made. TVA feels that other nitrogen materials should also be evaluated under tropical conditions.

Certain rock phosphates have been shown to be fairly effective sources of phosphorus when finely ground and applied to acid soils, but many farmers prefer a granulated product. Economics will discourage long-distance transport in favor of high-analysis materials. Rock phosphates then have promise only when locally available at low cost as a means to supplement other phosphate sources in certain areas and thus are really not the final answer to providing the optimum phosphate requirements in the tropics.

Should AID consider a proposal to really get at the problem of tailoring fertilizers for the tropics? Most researchers at TVA and the international cooperators will answer "yes" for several reasons, and point out the following problems yet to be solved:

1. There is a need for further information on the extent of nitrogen losses from flooded soils and the mechanisms involved.

2. There is need for research to increase the effectiveness of conventional sources of nitrogen under tropical conditions.

3. More information is needed on ways to make water-soluble phosphates more effective for acid tropical soils.

4. More comparative studies should be made of citrate-soluble, water-insoluble sources of P under tropical conditions. Some quite promising evidence is presented in this report relative to these sources for rice grown on acid soils in Thailand.

5. Further study should be made regarding agronomic effects of granulation of rock phosphates. Perhaps fine granules and/or partial acidulation may be in order.

6. Urea coated with sulfur only should be tested for rice and other crops. Such a coating would offer savings over the costs of a multiple-component coating.

7. Convenient and effective ways of adding micronutrients are still needed for some cropping situations in tropical areas.

8. Other nitrogen- and phosphate-containing materials such as urea-ammonium sulfate, urea phosphate, ammonium polyphosphates, urea-ammonium polyphosphates, and small granules of phosphate rock should be tested. TVA has the facilities for making these and almost any other potential fertilizer material in limited quantities. As improvements are made in SCU, these products should also be tested further.

9. The incorporation of fertilizers and pesticides and herbicides has only been briefly examined.

10. Improved methods of fertilizer application are needed.

It is recommended that AID continue to support TVA in development of improved fertilizers for the tropics so that the momentum gained in this initial and somewhat limited project will not be lost. The need for food to feed the world's population continues to grow.

Appendix

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UTILIZATION OF AGRONOMIC RESEARCH

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Papers Presented at Scientific Meetings

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Response by Paddy Rice to Rates and Sources of Applied Phosphorus. G. L. Terman, S. E. Allen, and O. P. Engelstad.

Effect of Sulfur-coated Urea Applications on Production of H_2S in Flooded Soils. J. J. Mortvedt and P. M. Giordano.

Annual Meeting of Association of Southern Agricultural Workers, February 2-4, 1970, Memphis, Tennessee.

Response of Paddy Rice to Rate, Source, and Time of Applying Labeled Phosphorus. G. L. Terman and S. E. Allen.

Release of Nitrogen from Sulfur-Coated Urea in Flooded Soil. P. M. Giordano and J. J. Mortvedt.

Meeting of Rice Technical Working Group, February 24-26, 1970, Beaumont, Texas.

Response of Rice to Several Zn Sources Applied Alone and with Micronutrient Fertilizers. P. M. Giordano.

Minimizing N Loss During Preflood Applications of N Fertilizers. R. D. Hauck.

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Performance of Sulfur-Coated Urea under Intermittently Flooded Rice Culture in Peru. P. S. Sanchez, A. Gavidia, G. E. Ramirez, R. Vergara, F. Minguillo, and J. Paredes. *In Press.*

Organized Meetings with Advisory Committee and Other Cooperators

Meetings have been held annually (1969, 1970, 1971, 1972) with the Advisory Committee and other invited participants. Information and data have been shared by all those in attendance. The number attending these meetings has varied from 15 to 40.

Seminars

Basically the same seminar lecture, "The TVA-USAID Program of Developing and Testing Fertilizers for Rice," has been given by O. P. Engelstad as follows:

At the National Institute of Agricultural Sciences, Tokyo, Japan, October 1, 1969.

At the International Rice Research Institute, Los Banos, The Philippines, October 7, 1969.

At the Agronomy Department, University of Hawaii, Honolulu. April 17, 1970.

TVA GREENHOUSE EXPERIMENTS ON RICE

165-B: Sources and Rates of Phosphorus for Rice. G. L. Terman and S. E. Allen.

165-C: Rice Response to Added Phosphorus as Affected by Flooding. O. P. Engelstad.

165-D: Response of Rice to P, Zn, and Lime. G. L. Terman and S. E. Allen.

203: N Sources for Rice: Effect of Preflood Incubation. R. D. Hauck and O. P. Engelstad.

203-A, 203-B: Evaluation of Several Soils for Growing Flooded Rice: Response to Added N. R. D. Hauck and O. P. Engelstad.

203-C: N Sources for Rice: Control of Nitrification. R. D. Hauck and O. P. Engelstad.

203-D: N Sources for Rice: Persistence of Nitrification Inhibitors. R. D. Hauck and O. P. Engelstad.

203-E: N Sources for Rice: Effect of Particle Size, Particle Hardness, and Number of Application Sites on Yield and N Content. R. D. Hauck and O. P. Engelstad.

203-F: N Sources for Rice: Effectiveness of SCU of Varying Coating Weight and Dissolution Rates. R. D. Hauck and O. P. Engelstad.

203-G: N Sources for Rice: Sequential of Slow-Release Sources. R. D. Hauck, O. P. Engelstad, and H. F. Stephenson.

203-H: N Sources for Rice: Effect of Sulfur-Coated Urea and Azide Inhibitors. R. D. Hauck and H. F. Stephenson.

217: Recovery of Applied N by Rice as Affected by FeS Coatings of Sulfur-Coated Urea Granules. P. M. Giordano and J. J. Mortvedt.

217-A: Effect of Potassium Azide on Effectiveness of Sulfur-Coated Urea for Rice. P. M. Giordano.

218: Rate, Source, and Placement of P for Rice. G. L. Terman and S. E. Allen.

219, 219-A: Response of Rice to Labeled P at Different Soil P Levels. G. L. Terman and S. E. Allen.

219-B: Response of Rice to Labeled P, as Affected by Time of Application. G. L. Terman, S. E. Allen, and B. N. Bradford.

219-C: Response of Flooded Rice to P in Rock Phosphates Varying in Citrate Solubility. O. P. Engelstad and S. E. Allen.

224: Response of Rice to Nitrogen and Water Management. S. E. Allen and G. L. Terman.

224-A: Effect of Intermittent Flooding on Release of N from Sulfur-Coated Urea. O. P. Engelstad.

226:. Response of Rice to Several Zn Sources Applied Alone and with Fertilizers. P. M. Giordano and J. J. Mortvedt.

226-A: Response of Rice to Zn as Affected by Zn Source, Carrier, and Method of Application. P. M. Giordano and J. J. Mortvedt.

226-B: Response of Several Rice Varieties to P and Zn. P. M. Giordano and J. J. Mortvedt.

226-C, 226-D: Response of Rice to Zn Sources. P. M. Giordano and J. J. Mortvedt.

226-E, 226-F: Response of Rice Varieties to Zn. P. M. Giordano and J. J. Mortvedt.

235: Response of Rice to Forestry-Grade Sulfur-Coated Urea. O. P. Engelstad and S. E. Allen.

242: Response of Rice to Various N Sources, as Affected by Placement, Soil pH and Preplant Incubation. O. P. Engelstad.

245: Response of Rice to Zn, as Affected by Moisture Regime and Zn Placement. P. M. Giordano, J. J. Mortvedt, and G. Osborn.

259: Response of Rice to S as Affected by Flooding. G. L. Terman.

SUMMARIES OF REPORTS ON TVA GREENHOUSE EXPERIMENTS

165-B December 1968

Sources and Rates of Phosphorus for Rice

G. L. Terman, S. E. Allen, and Greenhouse Staff

Nato rice was grown for 16 weeks to maturity on flooded, unlimed Mountview silt loam to evaluate various soluble and phosphate rock (PR, -200 mesh) P sources applied at rates of 50, 100, and 200 mg/pot (5 kg of soil). The P sources were CSP, monoammonium phosphate (MAP), ammonium polyphosphate (APP) and several phosphate rocks (PR). Effectiveness of the P sources in terms of total dry matter produced in straw and grain was in the order: CSP = MAP = APP (all 6+9 mesh) > CSP (35 mesh) = Gafsa PR = North Carolina PR > Florida PR > S-coated SCP (-6+9 mesh) = Morocco PR = Togo PR > Quebec PR = no applied P. Total uptake of P was in essentially the same order.

Numbers of tillers and heads were doubled by the more soluble P sources, as compared to no applied P and the less soluble phosphate rocks. Response by rice to granule size and solubility of P fertilizers was similar to that previously found for other crops grown on unflooded soils. However, lower rates of P apparently are needed for rice to obtain optimum response.

165-C February 1969

Rice Response to Added Phosphorus as Affected by Flooding

O. P. Engelstad

A greenhouse pot experiment was conducted to determine the effect of flooding on the response of rice to added granular P sources varying in water solubility. The P sources, CSP and dicalcium phosphate (DCP), were mixed with unlimed Mountview silt loam as -6+10 mesh granules at rates to supply 50, 100, and 200 mg of P per pot. One series of pots was kept flooded and a second series was maintained at a moisture level of 22% by daily watering.

The results showed that water-soluble CSP was much more effective than the water-insoluble DCP. Increases in check yields and uptake indicated that soil P was made more available by flooding; however, the response curves were essentially shifted upward with little change in shape, which indicates some physiological effect of flooding on growth. Flooding probably increased soil P availability (by reduction of ferric phosphates) and also the plant vigor and requirement for P.

203 January 1972

Nitrogen Sources for Rice: Effect of Preflood Incubation

R. D. Hauck, O. P. Engelstad, and Greenhouse Staff

A greenhouse pot experiment with flooded rice was conducted on Mountview silt loam to determine whether grain yields from several N sources were related to their rates of nitrification during the preflood period. Of seven N fertilizers used, four of them—urea, urea-ammonium phosphate (UAP), APP, and diammonium phosphate (DP)—form alkaline solutions in the fertilizer-soil reaction zone. The remaining three—MAP, ammonium sulfate (AS), and ammonium chloride (ACl)—form acid solutions.

In soil of pH 5.5, grain yields and N contents of grain were lower from alkaline-forming, as compared to acid-forming materials. This was probably because the alkaline materials nitrified at a faster rate and, therefore, more nitrate derived from these materials was lost via denitrification. Differences among N sources increased with increase in N rate and period of incubation preceding flooding. In soil limed to pH 7.2, less grain was obtained from AS than from equivalent amounts of N from urea. In all cases, yield and N content of grain decreased with length of preflood incubation period, indicating losses of N from the system.

The results of this experiment are consistent with the observation that in acid field soils, AS usually is slightly more efficient than urea for direct-seeded rice.

203-A and 203-B February 1972

Evaluation of Several Soils for Growing Flooded Rice: Response to Added N

R. D. Hauck and O. P. Engelstad

Flooded rice was grown in greenhouse pots to evaluate several soils in terms of yield response to added N. The results obtained from these two experiments indicate that (from the sites sampled) Decatur sicl (from farm in Colbert County), Crowley sil, Mountview sil, Hartsells fsl, and Davidson sicl should be satisfactory soils for this use. Sango sicl from the TVA nursery showed a lower response, while a Decatur cl from another nursery site showed a lower yield level than the soils compared with it.

203-C and 203-D September 1972

N Sources for Rice: Chemical Control of Nitrification

R. D. Hauck, O. P. Engelstad, and Greenhouse Staff

Control of nitrification during the preflood incubation period increased total dry matter yield and apparent recovery of applied N by rice in a greenhouse experiment which simulated the practice of direct-seeded rice culture. Partial control was obtained through the use of either nitrification inhibitors or slow-release N materials. However, losses of N via nitrification-denitrification were only partly prevented. With 14 of 16 inhibitor-amended or slow-release materials studied, yields from preflood incubated pots were lower than in pots where these materials were applied to soil immediately before flooding. In the incubated series, urea treated with the nitrification inhibitors 'N-SERVE' and 'AM', mixtures of thiourea with urea, and the slow-release materials oxamide, IBDU, and SCU having a coating weight of 13% produced more total dry matter than untreated urea. Apparent recovery of applied N was highest with SCU having 19% coating for both the incubated and unincubated series, but dry matter yields were less than from the above slow-release and inhibitor-amended materials. Nitrification inhibitors were ineffective in preventing N loss (as measured by plant response to applied N) in soils subjected to intermittent flooding and draining.

203-E February 1972

Nitrogen Sources for Rice: Effect of Particle Size, Particle Hardness, and Number of Application Sites on Yield and N Content

R. D. Hauck and O. P. Engelstad

A marked particle size effect on dry matter yield was obtained for oxamide and IBDU but not for urea when these materials were added to unlimed (pH 5.4) Decatur silty clay loam 3 weeks before flooding. No significant yield differences were noted for -8+10 mesh particles of these N sources added to soil limed to pH 6.5.

Rice responded to increasing rates of N as AS, with a maximum response near the 1,200 mg N rate (equivalent to about 480 pounds of N/acre). Soil pH levels in both soils decreased approximately one unit in pots which received the heaviest (1,500 mg) rate of N.

About 74% of the variation in average dry matter yield could be explained by variation in number of tillers.

Although dry matter responses to added N were considerable, grain yields were considerably lower than from rice grown under more favorable seasonal conditions. Because of this, portions of this experiment will be repeated.

203-F March 1972

N Sources for Rice: Effectiveness of SCU of Varying Coating Weight and Dissolution Rate

R. D. Hauck, O. P. Engelstad, and Greenhouse Staff

Pilot-plant samples of SCU varying in coating weight and dissolution rate were compared as N sources for rice after a preflood incubation period of 3 weeks. Small but significant differences in dry matter yields were observed among the SCU sources, with a positive relationship between dissolution rate and yield. Crop absorption of applied N was similar in amount (about 40%) for the most soluble SCU sources and uncoated urea or AS. No significant differences were obtained between urea and AS when banded or mixed throughout the soil. Preflood incubation of 3 weeks decreased apparent recovery of added N from about 60% to about 40%. Abnormally low grain yields were obtained in many replicate pots because of adverse growing conditions. As a result, wide variations among replicates limit the usefulness of the above data.

217 October 1969

Recovery of Applied N by Rice as Affected by FeS Coatings of Sulfur-Coated Urea Granules

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

SCU was compared with granular urea as a source of N for rice grown on flooded Mountview sil (pH 5.1). Incubation of SCU in moist soil for 2 weeks prior to flooding and planting resulted in maximum dry matter production and uptake of N by rice. Continuous flooding resulted in heavy coatings of FeS on the granules but little or no release of N from the granules for subsequent uptake by rice. Analysis of the granules recovered from flooded uncropped pots at various times throughout the growth period indicated that the rate of N release is not affected appreciably by FeS formation when the soil is flooded.

217-A March 1970

Effect of Potassium Azide on the Effectiveness of SCU for Rice

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

Potassium azide (KN_3) was coated on SCU granules at concentrations of 0.5 and 1.5% to inhibit nitrification of released N during preflood incubation. However, the low dissolution rate of the substrate SCU in Mountview sil precluded evaluation in this experiment. A significant

portion of the N applied as urea and also NO_3-N in the soil was lost by denitrification upon flooding after 4 weeks' incubation in moist soil. Mixing KN_3 with the soil at a concentration of 6 ppm was not toxic to the rice and effectively reduced loss of NO_3-N from the soil.

218 October 1969

Rate, Source, and Placement of P for Rice

G. L. Terman, S. E. Allen, and Greenhouse Staff

Several P sources were compared at rates of 0, 10, and 20 ppm of P (0, 50, and 100 mg/pot) for Nato rice grown on flooded Mountview silt loam.

Highest yields of dry foliage, tillering, and uptake of P were obtained with CSP and nitric phosphate (NP) sources containing water-soluble P, $MgNH_4PO_4$ and fine colloidal $FePO_4$. Intermediate responses were obtained with granular $FeNH_4PO_4$, $ZnNH_4PO_4$ and colloidal $FePO_4$, fine colloidal $AlPO_4$ and crystalline $FePO_4 \cdot 2H_2O$. Lowest response resulted from granular DCP and crystalline $AlPO_4 \cdot 2H_2O$. Yields were significantly correlated with tillering in this experiment. Yields of dry matter were similar with mixed and surface-applied fine CSP and colloidal $FePO_4$, but P uptake was higher from the surface application.

219 and 219-A August 1969

Response of Rice to Labeled P at Different Soil P Levels

G. L. Terman, S. E. Allen, and Greenhouse Staff

Nato rice was grown on Mountview silt loam at the initial low P level, on this soil receiving preplant applications of P (medium and high P levels), and on Decatur silty clay loam (medium P level). CSP, CSP-DCP (2/1 mixture) and CSP-DCP (1/2 mixture) were all labeled with ^{32}P, granulated, and applied at rates of 50, 100, and 200 mg/pot (5 kg of soil). A duplicate series of treatments were included with the same unlabeled P sources but in which the soil was uniformly labeled with carrier-free ^{32}P. Response to applied P by flooded vs unflooded rice was also studied.

Dry matter yields and tillering increased markedly with amount of applied P on the low P soil, and slightly on the medium P Mountview soil. Response decreased with decrease in water solubility of the applied P at the low and medium soil P levels. There was no significant response on the high P Mountview or on the Decatur soil. Total uptake of P by the rice showed similar trends, except that uptake increased significantly at the medium soil P level with amount of P applied.

Percentages of plant P from the labeled fertilizer and uptake of fertilizer P increased in all situations with amount of applied P, decreased with decrease in water solubility of the applied P and decreased with increase in soil P level. Uptake of soil P increased markedly with increase in soil P level, but usually decreased slightly with increase in rate of applied P and with decrease in water solubility.

The objective of the split-root experiment (219-A) comparing ^{32}P rates and water regimes was not attained because of a toxic condition in the flooded soil.

219-B January 1970

Response of Rice to Labeled P, as Affected by Time of Application

G. L. Terman, S. E. Allen, and B. N. Bradford

Labeled P as a solution of CSP was injected into the soil or applied to the flood water to supply 50 or 100 mg of P for rice per pot (5 kg of Mountview silt loam) as follows: at time of transplanting (4 hills of 3 plants each per pot), 3 weeks later and 6 weeks later. The Mountview soils was used without (low P) and with a preplant P application to bring the soil to a medium soil test level.

On the low P soil, yields, P uptake, and tillering increased with rate of applied P but decreased with later date of application. On the medium P soil, yields, tillering, and uptake of P by the grain were rather similar among treatments. Uptake of P in the foliage and mature straw, however, increased with later date of application.

These results indicate that late-applied P is readily absorbed by the rice crop but is not effective for increasing yields.

219-C August 1970

Response of Flooded Rice to P in Rock Phosphates Varying in Citrate Solubility

O. P. Engelstad and S. E. Allen

A series of rock phosphates varying rather widely in citrate solubility was compared with fine and granular CSP as sources of P for flooded Nato rice in a greenhouse experiment with Mountview silt loam.

Direct seeding was practiced for two succeeding crops. In each case, flooding was delayed for 3 weeks after seeding.

Results indicated that the North Carolina rock phosphate was 85-90% as effective as granular CSP; central

Florida, north Florida and Idaho rocks were intermediate in effectiveness (30-46% as effective as granular CSP), while Tennessee, Missouri, and Indian (Udaipur deposit) rocks were almost completely ineffective.

Response patterns and yield levels showed similar trends for both crops.

219-D and 219-E September 1972

Response of Rice to Granular Phosphates of Low Solubility

O. P. Engelstad, S. E. Allen, and Greenhouse Staff

Experiments were conducted to evaluate granular urea-rock phosphates and granular partially acidulated rock phosphates as sources of P for flooded rice. These were compared with their rock phosphate counterparts in both fine and granular form and with granular CSP.

The granular urea-rock phosphates were rather poor sources of P in these experiments. Presumably this is related to the lack of sufficient surface area exposed to the soil to bring about adequate P dissolution.

The granular partially acidulated rock phosphates were intermediate in effectiveness and offer somewhat more potential. Granule size had relatively little effect on response.

224 August 1970

Response of Rice to Nitrogen and Water Management

S. E. Allen, G. L. Terman, and Greenhouse Staff

Several N sources were compared for Nato rice at rates to supply 0, 400, and 800 mg of N/pot (5 kg of Mountview sil) in 4 water management series: flooded 3, 6, and 10 weeks after planting and not flooded (maintained at 22% moisture, about 60% water saturation).

Numbers of viable stems and tillers, yields and N uptake by straw alone and grain plus straw all increased markedly with increase in amount of applied N. These yield attributes decreased with water management as follows: flooding after 3 weeks > flooding after 6 weeks > flooding after 10 weeks > or = no flooding. Grain yields increased with amount of applied N but were low and not consistent with N source or water management treatments. Under flooding after 3 weeks, urea + N-serve and SCU with 13% coating alone and with microbicide produced highest yields of grain + straw. Differences among N sources with other water management systems were small and inconsistent.

224-A June 1971

Effect of Intermittent Flooding on Release of N from Sulfur-Coated Urea

O. P. Engelstad and Greenhouse Staff

Conventional spheriodized urea and two SCU materials, regular and large sizes, were added to Mountview and Crowley silt loam soils and subjected to various moisture regimes (incubation treatments) over a period of 4 weeks. Nato rice seedlings were transplanted to the treated pots and flooded. Cyclical flooding and drying during incubation reduced the release rate of N from SCU, as previously reported in Greenhouse Experiment 217. Though dissolution rates in H_2O were similar, the larger size of SCU prepared from forestry grade Cominco urea showed consistently lower release rate in flooded soil than the regular size, regardless of incubation treatment.

A 2- or 4-week unflooded incubation period enhanced the subsequent release rate of SCU during the flooded growth period in Crowley soil; this effect was not evident in the Mountview soil. Rate of N release from SCU in Mountview soil was generally higher than in Crowley soil.

Apparent recoveries of N applied as uncoated urea ranged from 39 to 63%. More loss of N was apparent from Mountview than from Crowley soil.

226 March 1970

Response of Rice to several Zn Sources Applied Alone and with Fertilizers

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

A greenhouse experiment was conducted to compare the agronomic effectiveness of several Zn sources applied alone or with various macronutrient fertilizers at a 2% Zn content. The fertilizers were mixed with Nolichucky scl limed to pH 7.5 at rates of 0, 10, and 40 mg Zn per pot.

Both yields and uptake of Zn by 11 week old Nato rice plants were similar from $ZnSO_4$, ZnO, and ZnEDTA granulated with urea ammonium polyphosphate (UAPP). AS was an equally effective carrier of ZnO and ZnEDTA, but a less effective carrier of $ZnSO_4$. When applied alone, uptake of Zn from finely ground $ZnSO_4$ and ZnO was equal whereas Zn uptake from ZnEDTA was significantly less. When $ZnSO_4$ was granulated with several macronutrient fertilizers the uptake of Zn was in the following order: urea = UAPP > AS = CSP > UAP.

Recovery of Zn from the soil after harvest by 0.1 *N* HCl was much higher than by a DTPA solution; both extractants removed more Zn from ZnO than from $ZnSO_4$ or ZnEDTA treated soils.

226-A October 1970

Response of Rice to Zn as Affected by Zn Source, Carrier, and Method of Application

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

Granulation of urea, UAP, UAPP, and AS with either ZnO or $ZnSO_4$ resulted in similar increases in yields and uptake of Zn by Nato rice plants grown on Nolichucky scl (pH 8.0). Moist incubation of the fertilized soils for 4 weeks prior to flooding reduced dry matter by 20-30%, but this was attributed to N loss by denitrification rather than Zn immobilization.

Several methods of $ZnSO_4$ application proved to be equally effective for direct seeded rice. These included (1) mixing with the soil, (2) adding to the flood H_2O, (3) adding to the flood H_2O in small increments at weekly intervals, and (4) coating on the seed. Higher concentrations of Zn in direct seeded than in transplanted seedling rice suggest the requirement for Zn is most critical during the early seedling stage.

226-B November 1970

Response of Several Rice Varieties to P and Zn

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

Several varieties of rice were grown in the greenhouse on flooded Nolichucky scl (pH 8.0) fertilizer with various rates of P and Zn. There was very little difference among the varieties in response to applied P. However, growth reduction due to Zn deficiency was in the order: Bluebelle > Bluebonnet-50 > Dawn > Nato > Calrose. The concentration of Zn in Bluebelle, the most responsive variety to Zn, was higher than that in Calrose, the least responsive variety, with or without applied Zn. Uptake of Fe and Mn was not affected by the P and Zn treatments, nor did it differ among varieties.

226-C and 226-D January 1972

Response of Rice to Zn Sources

P. M. Giordano, J. J. Mortvedt, and Greenhouse Staff

226-C—Several finely ground sources of Zn were mixed with limed Crowley sil (pH 7.5). Bluebelle rice was grown to maturity under continuous flooding. These was essentially no increase in yield of straw or grain with any source of applied Zn. Also, Zn content of grain was unaffected by Zn application. Only ZnO increased the uptake of Zn by rice straw when applied at a rate of 1 ppm; $ZnO{\cdot}ZnSO_4$ (60% H_2O-soluble) also increased uptake when applied at 4 ppm Zn. Despite the poor response to Zn in this experiment, there is further evidence that ZnO is probably a superior source of Zn for flooded rice.

226-D—Six granular macronutrient fertilizers containing 2% Zn as ZnO were applied to limed Crowley sil (pH 7.5). Direct-seeded Bluebelle rice was grown to maturity under continuous flooding. Although there appeared to be a slight yield response with both straw and grain at the 4 ppm over the 1 ppm rate of Zn, the check values were generally highest. Similarly, Zn uptake by the no-Zn check plants was greater than by the Zn-treated plants. Possibly Zn contamination of the checks may have occurred.

226-E and 226-F January 1972

Response of Rice Varieties to Zn

P. M. Giordano, J. J. Mortvedt, G. Osborn, and Greenhouse Staff

Two greenhouse experiments were conducted in which several rice varieties were grown on flooded soil There was no increase in dry matter production with any rice variety in experiment 226-E, although Zn uptake increased with rate of applied Zn in most varieties. In experiment 226-F all varieties responded to Zn but to varying degrees. Both straw and grain yields of several varieties, especially Bluebelle, were increased by addition of ZnO. Furthermore, heading and maturation were delayed due to Zn deficiency mainly in early maturing varieties. Germination percentage of harvested grain was reduced in some instances where Zn was not applied even though there was no visual indication of reduced yield or delayed maturity.

235 August 1971

Response of Rice to N in Large Sulfur-Coated Urea Granules Varying in Release Rate, As Affected by Preplant Incubation

O. P. Engelstad and S. E. Allen

The release of N from large-sized SCU made from Cominco forestry grade urea was studied in flooded Mountview silt loam, using sequential N uptake by rice as the indicator of release. Release rates were 4.6%, 12.0%, and 21.0% in 7 days. Yields of rice at 3, 6, 9, and 12 weeks after transplanting indicated a good relationship between initial dissolution tests in H_2O and release of N in the flooded system. A pretransplant incubation for 3 weeks increased the rate of N release and resulted in higher N

recovery from the SCU during the subsequent flooding period. Incubation also resulted in marked increase in apparent losses of N from uncoated urea via the nitrification-denitrification route. Apparent recovery of uncoated urea-N decreased from 68 to 45% in the final harvest as a result of incubation treatment. The SCU materials of slower release rate (4.6 and 12.0%) showed little release of N after flooding. For systems such as used in this experiment, faster release rates are needed.

242 December 1971

Response of Rice to Various N Sources, as Affected by Placement, Soil pH, and Preplant Incubation

O. P. Engelstad and S. E. Allen

A greenhouse pot experiment with flooded rice was conducted on Sango silty clay loam to determine the effectiveness of granular AS, urea (2 sizes), and urea-ammonium sulfate as sources of N under various placement, soil pH, and incubation treatments. These sources were mixed with the soil or placed on the soil surface; applied to soil limed to pH 5.5 or 7.7; and incubated for 3 weeks in moist soil or applied immediately prior to flooding and transplanting.

The results showed only minor effects of source and soil pH; the dominant effects were associated with incubation and placement. Apparent recoveries of applied N were much lower from incubated systems as compared to unincubated; recovery of N was also consistently lower from surface than from mixed application. These results indicate that serious losses of N had occurred via the nitrification-denitrification processes as a consequence of preflood incubation and of placement at the oxidized soil-water interface.

245 September 1971

Response of Rice to Zn, as Affected by Moisture Regime and Zn Placement

P. M. Giordano, J. J. Mortvedt, G. Osborn, and Greenhouse Staff

Bluebelle rice was direct-seeded in limed (pH 7.5) Crowley sil fertilized with varying rates of P and Zn. After emergence of the seedlings the crop was grown either in moist (upland) or flooded soil for 9 weeks.

In general, dry matter production of rice foliage was about 2-fold higher from crops grown under flooded rather than under upland soil conditions. Growth responses to both P and Zn were obtained, although only a slight increase in growth occurred at Zn rates beyond 1 ppm. Mixed and surface applications of Zn were effective for flooded rice, whereas mid-depth placement was unsatisfactory; both surface and mid-depth placements were less effective than mixing under upland soil conditions.

The percentage recovery of fertilizer Zn was greater under flooded than under upland moisture regimes, especially at the highest rate of applied P. Likewise, uptake of P was higher with flooding. Interactions between P and Zn in rice appear to be more significant in upland than in flooded soils.