AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY
Agriculture AF25-0000-0000

B. SECONDARY
Soil fertility,fertilizers,and plant nutrition

2. TITLE AND SUBTITLE
Rock phosphates for flooded rice,an agronomic-economic analysis

3. AUTHOR(S)
Engelstad,O.P.

4. DOCUMENT DATE
1971

5. NUMBER OF PAGES
38p.

6. ARC NUMBER
ARC 633.18.E57

7. REFERENCE ORGANIZATION NAME AND ADDRESS
TVA

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

10. CONTROL NUMBER
PN-RAA- 216

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Flooding
Phosphate deposits
Rice

13. PROJECT NUMBER

14. CONTRACT NUMBER
PASA RA (QA) 5-69 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

7

TVA 140

Preliminary Data - Not for Publication

ROCK PHOSPHATES FOR FLOODED RICE

An Agronomic - Economic Analysis

O. P. Engelstad
Soils and Fertilizer Research Branch
Tennessee Valley Authority

SUMMARY

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

A procedure is presented which enables one to make the choice of P source on the basis of both agronomic effectiveness and ratios of prices at the farmer level. Preliminary indications are that if the cost of P in triple superphosphate (TSP) is more than twice as expensive as that in the more soluble rock phosphates, the latter sources could be feasible alternatives for rice on acid soils.

Residual data are presented which indicate that the same general pattern of effectiveness among sources persists through the second crop as found for the first crop. The residual effectiveness of TSP remained higher than that of the rock phosphates; however, the relationship between initial citrate solubility of the rocks and relative effectiveness in the second crop was rather poor. Disadvantages associated with rock phosphates, such as low analysis and often lower limiting yield levels, are also discussed.

Prepared January 1971.

BACKGROUND

Over the years, considerable debate has been devoted to the question of rock phosphates versus acidulated phosphates for certain regions of the developing world. While it is generally accepted that the various water-soluble phosphates are suitable for a wide spectrum of soil and crop conditions, there are situations in which certain rock phosphates are often satisfactory. Such may be the case for flooded rice grown on acid soils; rock phosphates are often used because they are lower in cost than the "processed" forms.

As a part of the program conducted under the TVA-AID project, "Tailoring of Fertilizers for Rice," a series of rock phosphates is being evaluated for flooded rice in various developing countries, including Thailand. Six rock phosphates (U. S. sources) form the basis for these experiments and represent the possible range of citrate solubility found among known world deposits. While other rock phosphates of similar composition from other countries could have been used, these particular materials were easier to obtain in finely ground form and in the quantity needed. Cooperators were also encouraged, however, to compare similarly prepared native or locally available rock phosphates in the experiments whenever possible.

The purposes of this report are: (1) To present TVA laboratory and greenhouse data on these and other rock phosphates; and (2) To present an agronomic-economic analysis of rice yield data obtained with some of these same phosphates in Thailand.

PROCEDURE AND RESULTS

TVA Studies

A large number of rock phosphates have been characterized in the TVA laboratories. These represent the majority of the known world deposits. Greenhouse experiments have been conducted under standardized conditions to evaluate selected sources for flooded rice. These are listed in Table 1, along with P_2O_5 content and citrate solubility. These sources are arranged in order of decreasing citrate solubility; that is, as discussed later, an important parameter reflecting the availability of rock phosphates for rice. Details regarding the procedure used in these greenhouse experiments are provided in the respective greenhouse reports (attached as appendixes to this report).

Table 2 contains the average yield of dry matter for each source as well as the relative agronomic effectiveness (RAE) values.[1/] These RAE values indicate a high correlation between citrate solubility and yield increase. The North Carolina and Tunisian rocks were 84-89% as effective as TSP; the remainder were substantially lower in effectiveness.

Further analyses of these data are presented in the greenhouse reports.

Thailand Field Experiments

Using the U. S. sources mentioned previously, two experiments were established in 1969 on wet-season rice on locations near Bangkok,

---

1/ These RAE values are calculated by dividing the respective yield increases over the check by the same for TSP and multiplying by 100. Thus, TSP serves as a standard for comparison.

Thailand. This was a cooperative effort involving the International Rice Research Institute, TVA, USAID, Kasetsart University, and the Rice Department of The Ministry of Agriculture. The two locations are described below.

Klong Luang Rice Experiment Station- The soil was developed from brackish water sediments. It possesses heavy clay texture throughout the profile with a black upper horizon. This soil belongs to the Ongkarak series and possesses a "Cat Clay" horizon at the depth of 40 centimeters. The fertility of the soil is relatively low. Analytical results on the "plow layer" of the Ongkarak soil are: pH (1:1), 4.5-4.8; organic matter, 1.7%; available P, 4.5 ppm; C.E.C., 18.6 meq/100 g; and base saturation, 61%.

Bangkhen Rice Experiment Station--The Bangkhen soil derived from the alluvial sediments of brackish water marine clay can be found over the flood plain area. It has a heavy clay texture all through the profile. The fertility of this soil is moderately high. Analytical results on the "plow layer" of this soil are: pH (1:1), 5.6-5.9; organic matter, 2.5%; available P, 4.4 ppm; C.E.C., 23.4 meq/100 g; and base saturation, 86%.

Rice Variety--A rice variety known as RD 1 was used in both experiments. RD 1 is a cross between Leuang Tawng and IR 8. Leuang Tawng is a Thai variety known for being nonsensitive to photoperiod.

Experimental Method - First Crop--The design used in these experiments consisted of a split-plot design with 4 nonzero rates of phosphorus (25, 50, 100, and 200 kg P_2O_5/ha) applied as main plot treatments and the sources of phosphorus as subplot treatments. There were two check plots in each replicate. The extra check plot was

included to permit the application of fresh TSP standard for the succeeding crop; the purpose of this was to permit accurate measurement of the residual effectiveness of the rock phosphates. Phosphorus fertilizer materials were broadcast on the mud and then incorporated in the soil during the last harrowing. At time of transplanting, immediately before the last harrowing, 100 kg/ha of N as ammonium sulfate (AS) and 40 kg/ha of K_2O as potassium chloride were applied. A total of 40 kg/ha of N as AS was applied later in two topdressings with about 5 cm depth of water on the plots.

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

Results - First Crop--The average yields of rough (unhulled) rice for the two locations are provided in Table 3 and plotted in Figures 1 and 2. While the greatest yield response was obtained at Klong Luang, a quite satisfactory yield response was obtained to added phosphorus at Bangkhen as well. As also found in the TVA greenhouse experiment, a high correlation was found between citrate solubility and yield increase at both locations. These relationships are shown in Figure 3. A simple linear regression model accounted for 92% and 88% of the variation in RAE at Klong Luang and at Bangkhen, respectively. The pattern of the relationship was quite consistent between the two locations, the only difference being shown in the slope of the line. That is, the effects of individual differences among the rock phosphates were reflected in similar fashion at the two locations.

The RAE values based on yield increases (TSP = 100) are given in Table 4. These values reflect the agronomic effectiveness of these various sources relative to the TSP standard; however, these should be supplemented by an economic analysis before rational choices can be made.

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

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

or

$$REE = RAE \times \frac{\text{Price of TSP/kg } P_2O_5}{\text{Price of RP/kg } P_2O_5}.$$

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

There is a temptation to calculate REE values for the Thailand data; however, fertilizer prices and freight charges are currently in such a state of flux that such figures may be meaningless, or worse, misleading.

The REE calculations were therefore used in a different way; they were used in preparing an indifference curve (Figure 4) wherein RAE values are plotted against P_{TSP}/P_{RP} ratios. The curve itself connects those points at which REE equals 100. When exactly on the curve, it makes no real economic difference what source is chosen.

To use this curve, one is referred first to Figure 5. That figure contains price ratios (P_{TSP}/P_{RP}) for some relevant price ranges of TSP and rock phosphate, where the assumed content of P as P_2O_5 was 46% and 32%, respectively. After one locates the particular price ratio

that suits the occasion, one then can go to Figure 4 and project upward from that ratio; knowing the RAE value (or estimating it from the curves in Figure 3, using citrate-soluble P content), one can then determine directly the best choice of source. For example, if the price ratio obtained from Figure 5 is 2.5 and the RAE value of the rock phosphate is greater than 40, the rock phosphate in question would be used. However, if the RAE value was less than 40, TSP would be a better choice. There are indications that if the P in the more soluble rock phosphates (North Carolina, north Florida, central Florida) is less than half as expensive as that in TSP, these rocks would be feasible alternatives to TSP on soils similar to those used in Thailand.

It should be pointed out that only a portion of the various yield response curves was used in this analysis, i.e., up to 50 kg per hectare. Beyond this rate, yield response was much less pronounced. It could be argued that at less than maximum yields, TSP would produce a certain yield at lower rates of P_2O_5 than would rock phosphate. This would especially be true for low rates of application. For example, at Klong Luang, 5500 kg of rice per hectare could have been produced with either 25 kg of P_2O_5 as TSP or 100 kg of P_2O_5 as some of the more reactive rock phosphates. It should be pointed out, however, that this is the yield level that would show the widest difference; such is the advantage of hindsight. Generally speaking, however, if the farmer wishes to use very low rates of phosphorus, he should use TSP or some other soluble source. There is a real possibility that use of low rates could occasionally result in significant losses in yield.

Residual Effects - Second Crop--These experiments were continued during the dry season of early 1970 to ascertain the residual effectiveness

of the various sources applied to the first crop. No new P was applied except for the fresh TSP standard mentioned above. The experiment otherwise was conducted in a manner similar to that followed in the first crop.

The yield data obtained are plotted in Figures 6 and 7. The response to both freshly applied and residual P was marked at the Klong Luang location and marginal at Bangkhen. In fact, at the latter location, the response is so small that little can be said regarding residual effectiveness.

Relative agronomic effectiveness values were calculated for the Klong Luang data using both the residual and freshly applied TSP as standards. These data are presented in Table 5. It is of interest to note that the superiority of TSP over the rock phosphates has persisted through the second crop. The more soluble rocks ranged from 56-74% as effective as residual TSP, and from 27-55% as effective as freshly applied TSP. The main difference in the residual effects is that, with the exception of the Missouri rock, the marked relationship between citrate-soluble P content of the rock phosphates and RAE has now largely disappeared.

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

These data indicate that (1) residual effects of all rocks except Missouri are substantial; (2) the relationship between RAE of

the rock phosphates and citrate solubility levels was largely obscured; and (3) the general superiority of TSP over rock phosphate in terms of effectiveness persisted through the second crop.

In view of the last conclusion, the procedure for selecting P sources described above is not really affected. Residual effects do not need to form part of that analysis. In calculating returns to investment in P fertilizer, however, residual effects should be included.

DISCUSSION AND CONCLUSIONS

It is recognized that farmers may well prefer to use higher analysis materials in granular form. Higher analysis may be of real importance where distance from the port is great and transportation facilities are poorly developed. This would work against rock phosphates and favor the higher analysis processed P or NP materials. Also, application of granular materials is usually preferable to application of powdered materials, whether applied by hand or machine. Such is more a matter of convenience than economics, however. At any rate, granulation would be expected to increase the effectiveness of TSP, and decrease the effectiveness of rock phosphate. It may be that cogranulation of such materials as urea and rock phosphate will be satisfactory; however, this product is as yet under study.

Another situation in which rock phosphates would be a disadvantage is where the farmer wished to attain the highest possible yields, regardless of cost. In this case, these and other results indicate that soluble phosphates should be used. Limiting (maximum) yield levels with rock phosphates are usually lower than those with the

soluble phosphates. Apparently the early growth stimulation from soluble phosphates cannot be duplicated by rock phosphates, even when applied at fairly heavy rates.

These points regarding the possible disadvantages of rock phosphates are not related here to reflect negatively on them, but merely to bring out the more relevant aspects of their use. While it is apparent from this analysis that certain rock phosphates do have a place in direct application, it is also true that they are much more limited and restricted in their uses than are the soluble phosphates.

These data suggest that the potential for rock phosphates be more thoroughly explored, especially in those areas where acid soils are used for rice production.

Table 1. Sources of Rock Phosphates, Their TVA Code Numbers, P_2O_5 Content, and Citrate Solubility.

Source	TVA Code Nos. Fundamental Research Branch	TVA Code Nos. Process Engineering	Total[1/] P_2O_5 %	Citrate Soluble[1/] P_2O_5, % of Total	TVA Greenhouse Experiment No.
North Carolina	MR-21	--	29.9	24	165-B
	MR-467	PR-3	29.9	26	219-C
Tunisia	MR-15	--	29.1	21	165-B
North Florida	MR-466	PR-4	32.4	20	219-C
Central Florida	MR-2	--	32.7	15	165-B
	MR-464	PR-2	32.7	16	219-C
Tennessee	MR-468	PR-5	30.1	15	219-C
Idaho	MR-465	PR-1	32.3	12	219-C
Morocco	MR-17	--	36.6	11	165-B
Togo	MR-14	--	36.6	9	165-B
Quebec	MR-12	--	40.5	6	165-B
India	MR-469	--	40.1	5	219-C
Missouri	MR-505	PR-6	34.7	1	219-C
TSP (-6+9)	--	--	52.4	99	165-B 219-C

1/ Analytical data from June 1969 Progress Report of Fundamental Research Branch, TVA. The AOAC procedure was used in this determination (neutral ammonium citrate solution).

Table 2. Yields of Dry Matter, As Affected by Source and Citrate Solubility; Also Relative Effectiveness Values Based on TSP = 100.

Source	Citrate Soluble P_2O_5, % of Total	Average Yield of Dry Matter[1] g/pot			Relative Agronomic Effectiveness[2]		
		Experiment 165-B	Experiment 219-C		Experiment 165-B	Experiment 219-C	
			Crop 1	Crop 2		Crop 1	Crop 2
North Carolina	24-26	57.2	38.0	36.0	89	84	87
Tunisia	21	56.8	--	--	87	--	--
North Florida	20	--	28.4	26.1	--	46	48
Central Florida	15-16	46.3	26.3	23.3	42	37	37
Tennessee	15	--	18.3	16.6	--	6	10
Idaho	12	--	22.9	24.2	--	24	41
Morocco	11	43.9	--	--	32	--	--
Togo	9	42.2	--	--	24	--	--
Quebec	6	38.2	--	--	7	--	--
India	5	--	15.3	15.7	--	0	6
Missouri	1	--	16.8	17.7	--	0	14
TSP	99	59.7	42.0	38.3	100	100	96
No P	--	36.6	18.9	14.1	--	--	--

1/ Averaged over three rates of P.

2/ Increase over check divided by same for TSP x 100.

Table 3. Effect of Sources and Rates of Various Phosphates on the Yield of Rice in Thailand. Wet Season, 1969.

Sources	P_2O_5 Added kg/ha	Yield of Rough Rice, kg/ha Klong Luang	Bangkhen
North Carolina	25	4989	4608
	50	5254	4999
	100	5327	5193
	200	5672	5382
North Florida	25	5036	4458
	50	5180	4468
	100	5881	5128
	200	5636	5078
Central Florida	25	4840	4159
	50	5148	4718
	100	5620	5085
	200	5644	5313
Tennessee	25	3795	3593
	50	4432	3945
	100	4720	3994
	200	5098	5105
Idaho	25	4417	3658
	50	5158	4470
	100	5195	4491
	200	5855	4636
Missouri	25	3257	3692
	50	2125	3651
	100	2024	4302
	200	1910	3900
TSP	25	5556	5225
	50	5960	5503
	100	6223	5561
	200	5866	5797
No P	0	2672	3380

Table 4. Relative Agronomic Effectiveness Values[1/] for Experiments in Thailand. Wet Season, 1969.

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

1/ Based on planimeter measurements of the area under yield response curves (above the check level) up to 50 kg rate of P_2O_5/ha (see Figures 1 and 2). This is the most sensitive region and less subject to the influence of other variables.

Table 5. Relative Agronomic Effectiveness Values for Residual Experiments in Thailand. Dry Season, 1970.

Source	Klong Luang[1] % of Residual TSP	Klong Luang[1] % of Fresh TSP	Bangkhen[2]
North Carolina	37	27	-
North Florida	74	55	-
Central Florida	63	47	-
Tennessee	72	53	-
Idaho	56	41	-
Missouri	0	0	-
TSP (Residual)	100	74	-
TSP (Fresh)	135	100	-

1/ Based on planimeter measurements of the area under yield response curves (above the check level) up to the 100 kg rate of P_2O_5/ha.

2/ Residual responses were not statistically significant.

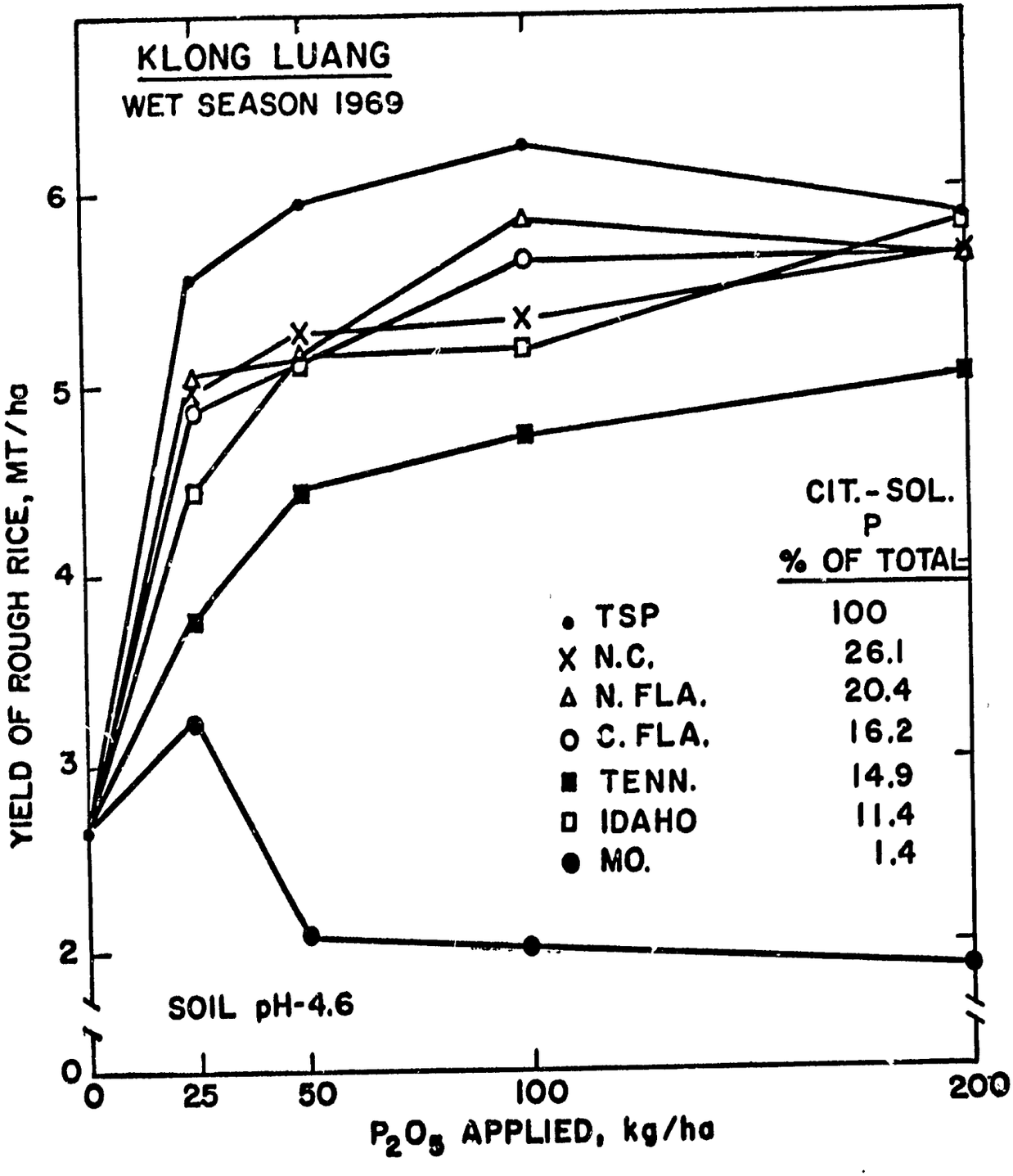

Fig. 1. Effect of various phosphorus sources on the yield of rough rice in an experiment at Klong Luang Rice Experiment Station, Thailand (wet season 1969).

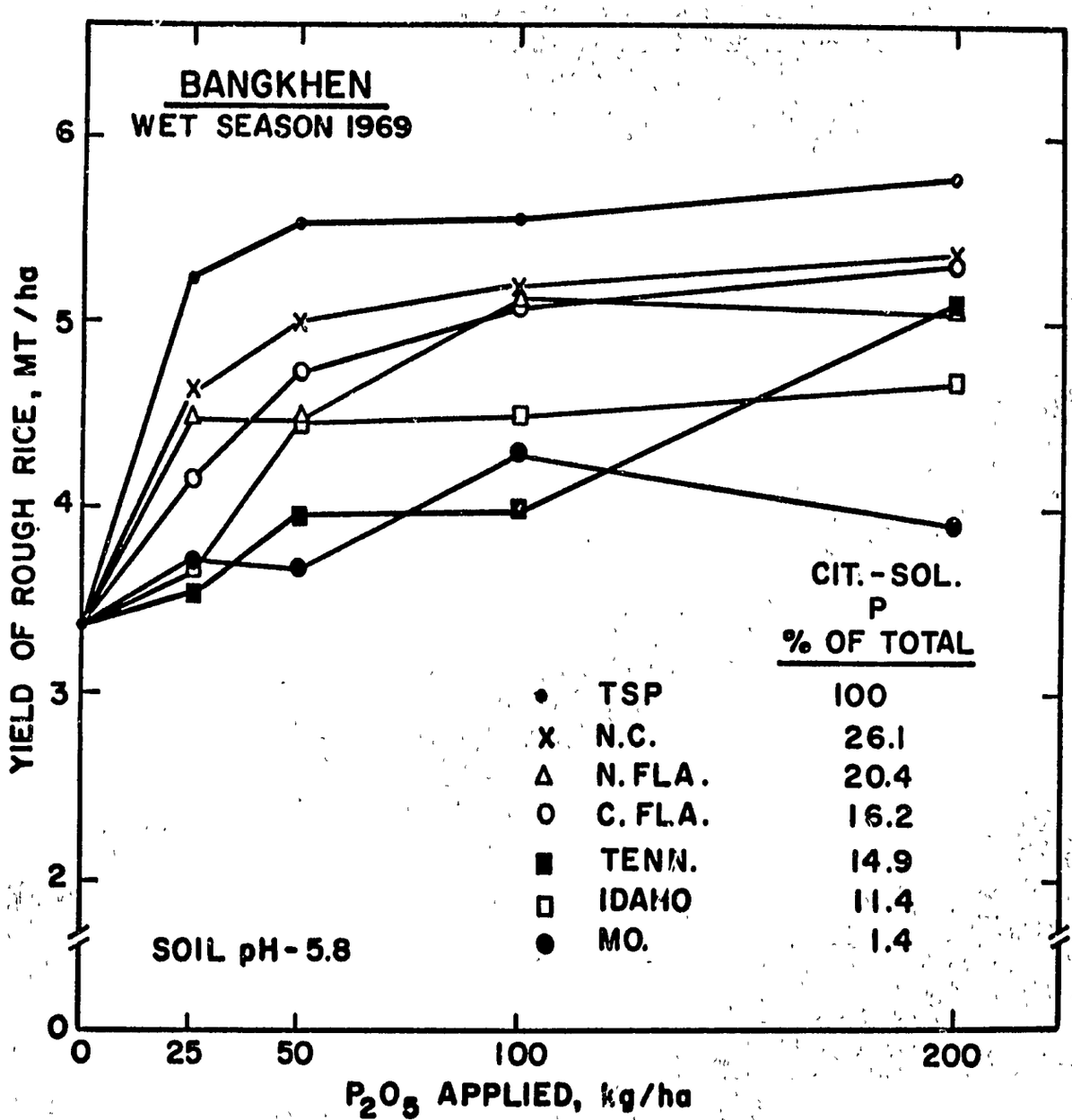

Fig. 2. Effect of various phosphorus sources on the yield of rough rice in an experiment at Bangkhen Rice Experiment Station, Thailand (wet season 1969).

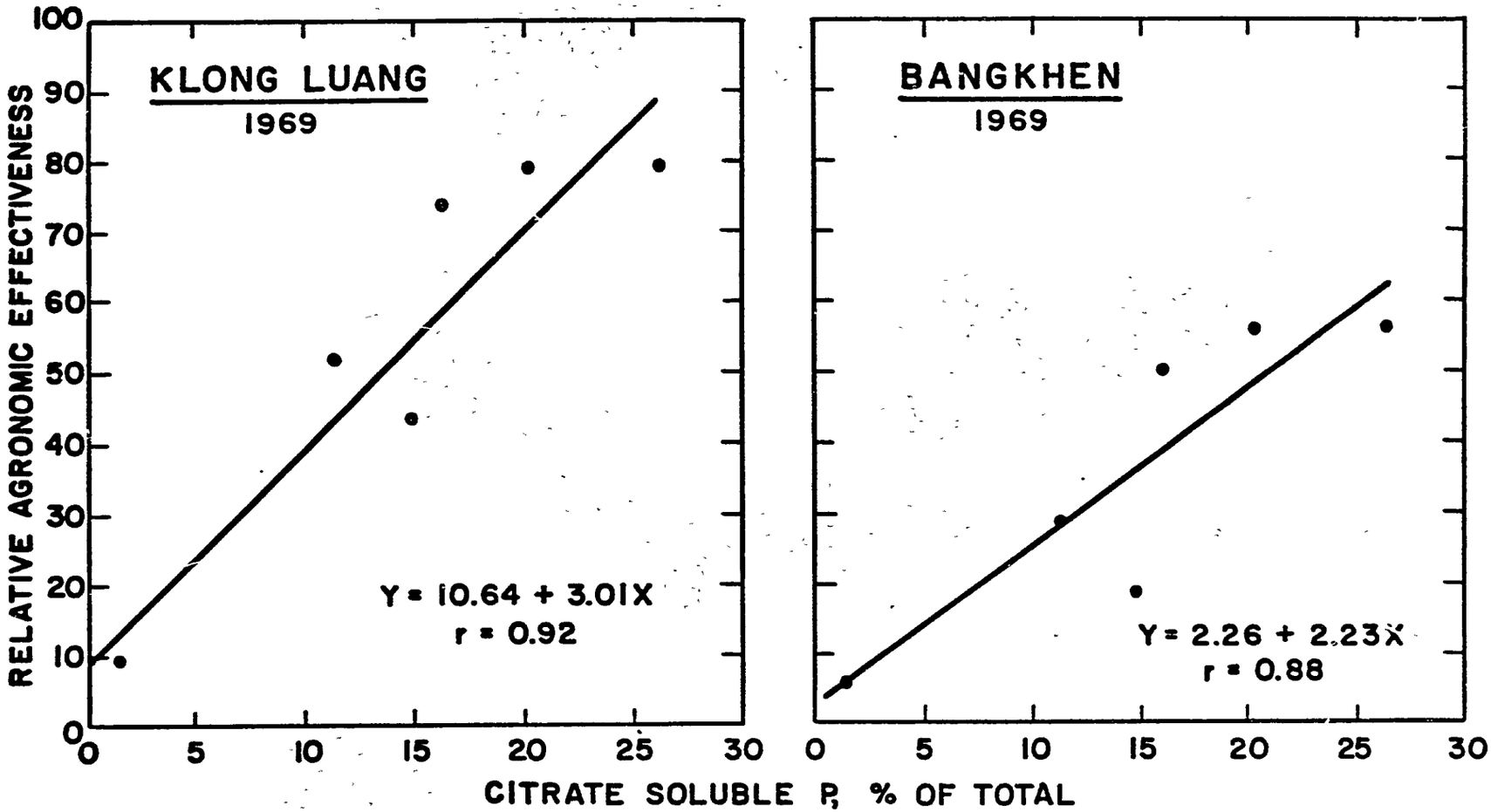

Fig. 3. Relationship between relative agronomic effectiveness (RAE) and dissolution of rock phosphates in ammonium citrate (wet season 1969).

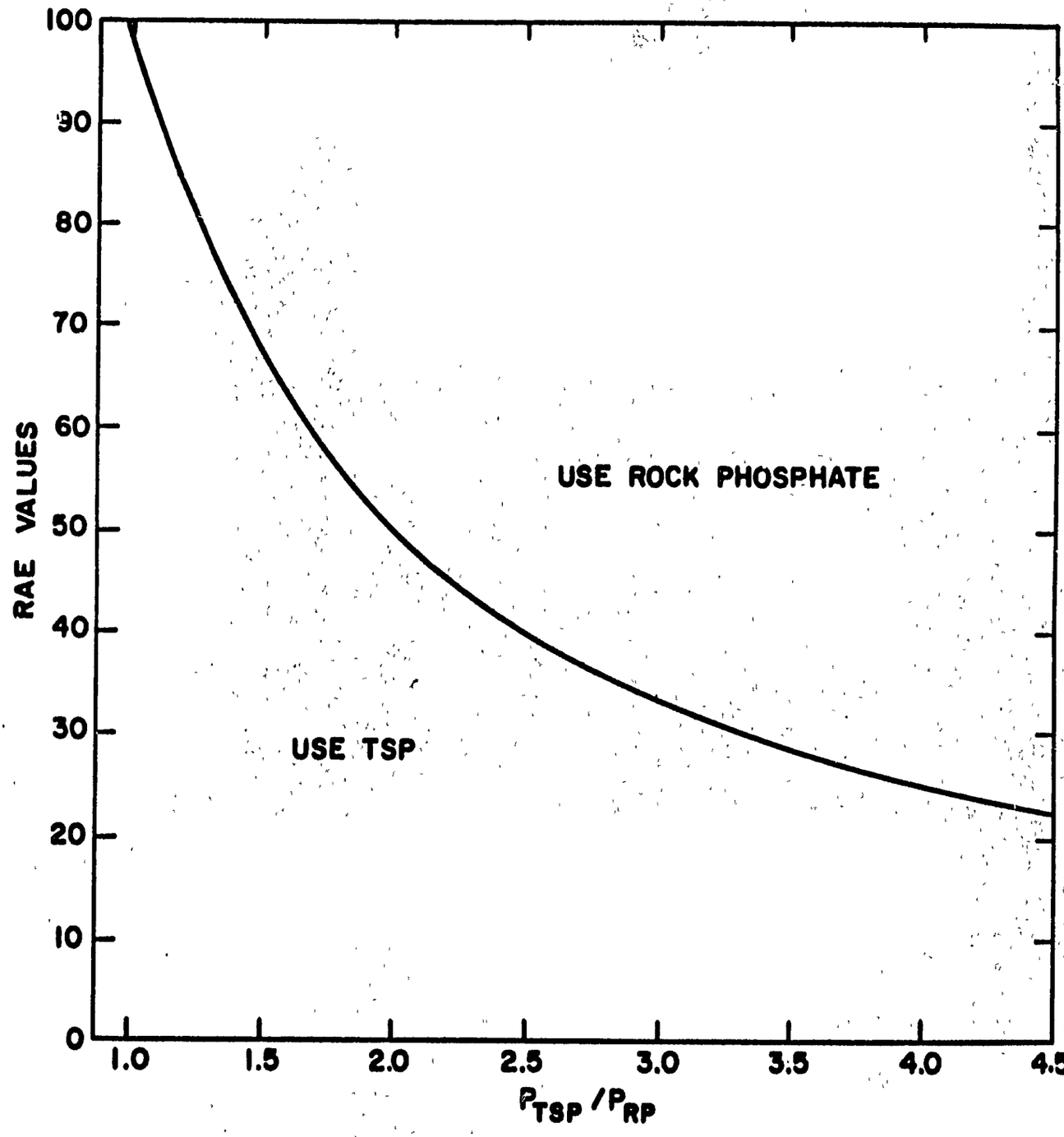

Fig. 4. Relationship between RAE values and the price ratios between TSP and rock phosphate. Such a figure can be used in making a choice between these sources.

TSP: Delivered Price/MT[1/]

ROCK PHOSPHATE: Delivered Price/MT[1/]	50	60	70	80	90	100	110
10	3.5	4.2	-	-	-	-	-
20	1.8	2.1	2.4	2.8	3.2	3.5	3.8
30	1.2	1.4	1.6	1.9	2.1	2.3	2.6
40	-	1.0	1.2	1.4	1.6	1.8	1.9
50	-	-	1.0	1.1	1.3	1.4	1.5
60	-	-	-	-	1.0	1.2	1.3
70	-	-	-	-	-	1.0	1.1

1/ These calculations are based upon assumed P_2O_5 contents of 46 and 32% for TSP and rock phosphate, respectively.

FIG. 5. PRICE RATIOS (P_{TSP}/P_{RP}) FOR SOME RELEVANT PRICE RANGES ($/MT OF MATERIAL) OF TSP AND ROCK PHOSPHATE

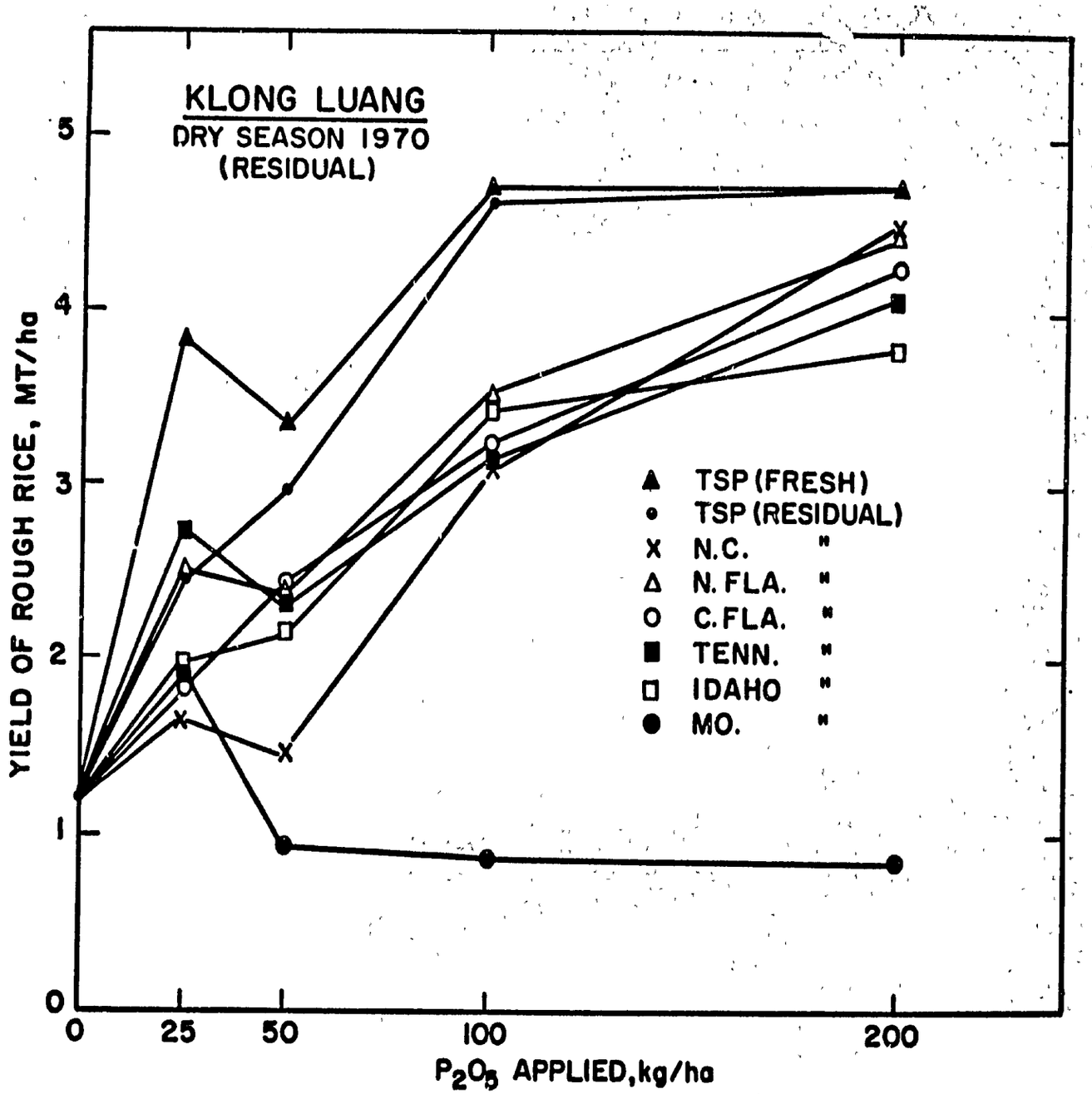

Fig. 6. The residual effectiveness of various phosphorus sources for a second crop of rice, as compared with that of freshly applied TSP. Klong Luang Rice Experiment Station, Thailand.

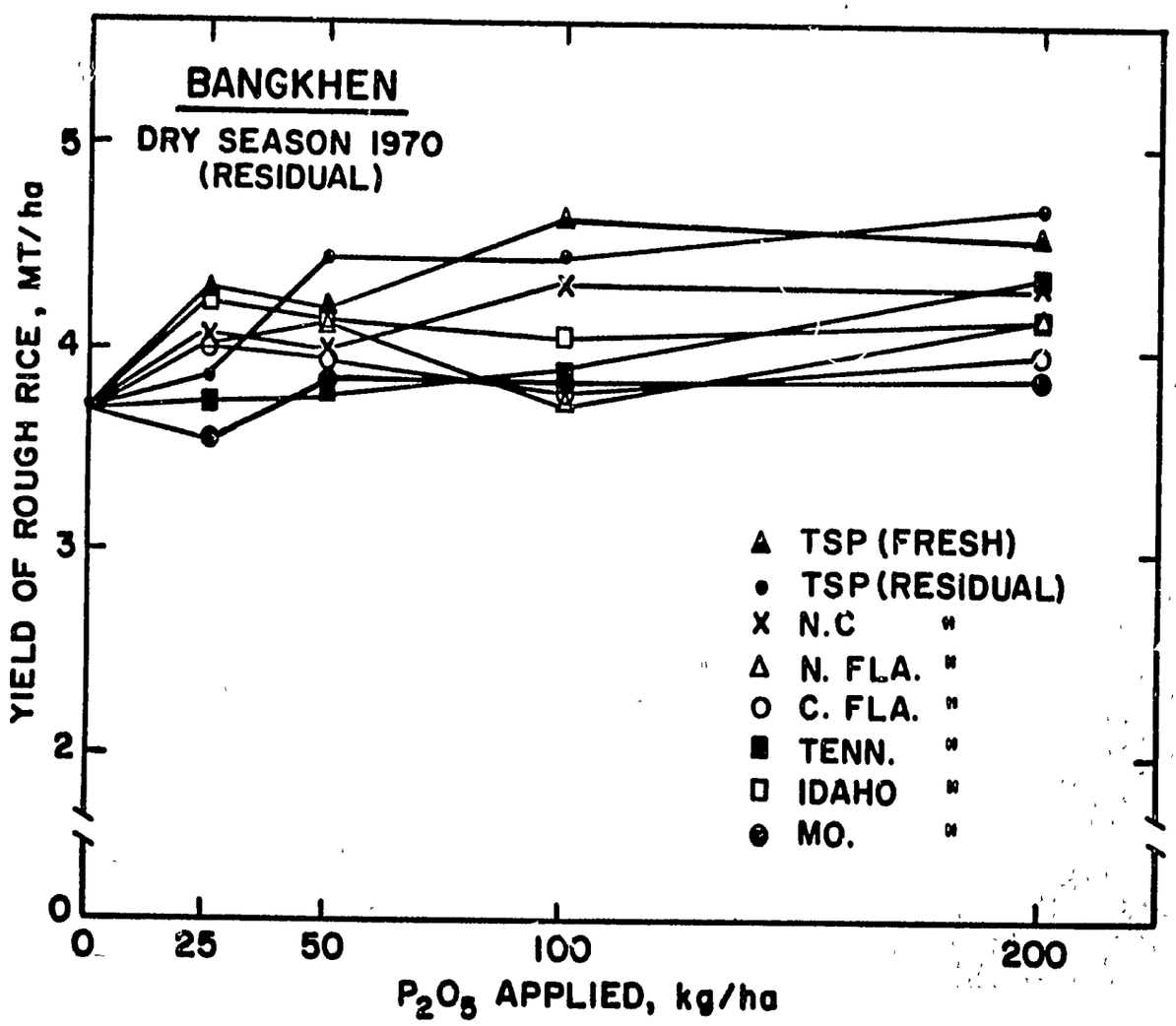

Fig. 7. The residual effectiveness of various phosphorus sources for a second crop of rice, as compared with that of freshly applied TSP. Bangkhen Rice Experiment Station, Thailand.

APPENDIXES

APPENDIX A

Preliminary TVA Data - Not for Publication

Report on Muscle Shoals Greenhouse Experiment 165-B:

SOURCES AND RATES OF PHOSPHORUS FOR RICE

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

December 1968

SUMMARY

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 concentrated superphosphate (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 CSP (-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.

BACKGROUND AND OBJECTIVE

Rice is commonly grown in various areas of the world under conditions where only low to moderate yield responses to applied P fertilizers result. The higher solubility of P in flooded soils, widespread use of fertile alluvial soils, and accumulation of residues over long periods help to explain the general low response to P. As a result, P fertilizers varying widely in solubility, together with P obtained from the soil, may all supply adequate P for rice.

The present experiment was conducted with rice grown on a very low P soil to evaluate fertilizers varying widely in solubility.

MATERIALS AND METHODS

Partial composition of the P sources compared in the experiment were as follows:

P Source and Mesh Size[1/]	Total P, %	Citrate Soluble P, % of Total
CSP (concentrated superphosphate), -35 and -6+9	20.7	99
CSP, S-coated, -6+9	14.8	-
MAP (monoammonium phosphate), -6+9	27.0	100
APP (ammonium polyphosphate), -6+9	27.4	100
Gafsa PR (phosphate rock), -200	12.7	21
N. C. (North Carolina) PR, -200	13.1	24
Florida PR, -200	14.3	15
Morocco PR, -200	16.0	11
Togo PR, -200	16.0	9
Quebec PR, -200	17.7	6

1/ The various phosphate rocks were obtained from J. R. Lehr.

Unlimed Mountview silt loam (5 kg/pot), pH 5.0, was used for the experiment. The following were mixed with the soil per pot: 600 mg of N as $(NH_4)_2SO_4$, 200 mg of K as K_2SO_4, 250 mg of complete micronutrient mixture and the P sources to supply 50, 100, and 200 mg of P. These treatments and a no-P check were replicated 3 times.

The Nato variety of rice was germinated in sand and grown to a height of 15 cm before transplanting to the pots. On June 25, 1968, the pots were flooded with deionized water and 4 groups of 3 plants each transplanted per pot the next day. Water was maintained at a depth of 5 cm over the soil until harvest on October 15. At this time grain was mature in pots receiving the more soluble P fertilizers. Glumes were still green and the grain poorly filled on pots receiving no P, on pots with the less soluble PR

and S-coated CSP sources and on late tillers resulting from all sources. Counts were made of the number of seed-bearing heads just prior to harvest. Dry weights and total P contents of the grain and straw were determined.

RESULTS AND DISCUSSION

Yields of dry matter and uptake of P in the rice straw and grain and the number of heads with grain, as affected by source and rate of P, are shown in Table 1.

Tillering

The more soluble P sources at the higher rates of addition doubled the number of grain-bearing heads per pot (Table 2), as compared to no applied P. Numbers of heads did not increase appreciably with the less-soluble PR sources and S-coated CSP. The number of heads also indicates the degree of tillering, since each stem bears one head, except for the later and weaker tillers, which did not always bear filled rice grains.

Dry Matter

Most of the increases in grain yields over no applied P were obtained by the lowest rate of P (50 mg/pot). This resulted in rather flat response curves for grain, which were higher for the more-soluble sources. Yields of dry straw, however, increased curvilinearly with all rates of the more-soluble P sources. With the less-soluble P sources, the straw responses were low.

Mean yields for the 50, 100, and 200 mg P rates (Table 2) were considered to be satisfactory for evaluating the P sources. For total yield of dry matter, these ranked in the order: CSP (-6+9 mesh) = MAP = APP > CSP (-35 mesh) = Gafsa PR = N. C. PR > Florida PR > S-coated CSP = Morocco PR = Togo PR > Quebec PR = no P. This is the same order as the decrease in citrate solubility of P in the PR sources. Grain yields averaged 26% of the total dry matter yield for the 6 more effective and 18% for the 6 less effective treatments.

P Uptake

Uptake of P by grain and straw increased linearly with amount of applied P. Mean total uptake for the 3 P rates (Table 2) gives about the same order of effectiveness of the various P sources as was found for total dry matter yields: CSP (-6+9 mesh) = MAP = APP > CSP (-35 mesh) = Gafsa PR = N. C. PR > Florida PR = S-coated CSP = Morocco PR = Togo PR > Quebec PR = no P. Content of P in the grain averaged 61% of the total uptake for the 6 more effective and 53% for the 6 less effective treatments.

The higher percentages of the total P uptake in the grain than was true for grain as percentages of the total dry matter yields indicate that some other growth factor (probably insufficient N supply) was limiting the grain yields.

Conclusions

Results from this experiment indicate that responses by rice to water solubility and granule size of P fertilizers follow the same trends as have been found for other crops grown on nonflooded soils. That is, yields of both rice grain and straw were highest with granular water-soluble sources, lower with fine CSP, and lowest with the less soluble phosphate rocks. The main difference seems to be the lower rates of P required for rice. This seems to be due to higher solubility of both soil and applied P in flooded soils.

Table 1. Yields of dry matter and uptake of P in rice straw and grain.

P Source	Mesh Size	P Applied, mg/pot	Yield of Dry Matter, g/pot			No. of Heads/ Pot	P Uptake, mg/pot		
			Straw	Grain	Total		Straw	Grain	Total
CSP	-35	50	39	12	51	20	14	21	35
		100	44	13	57	24	19	24	43
		200	46	16	62	23	26	36	62
CSP	-6+9	50	40	14	54	21	14	24	38
		100	44	17	61	23	15	29	44
		200	48	16	64	24	28	41	69
S-coated CSP	-6+9	50	32	6	38	12	17	14	31
		100	34	4	38	13	20	13	33
		200	37	8	45	13	18	19	37
MAP	-6+9	50	37	16	53	20	16	29	45
		100	44	17	61	24	20	31	51
		200	48	17	65	24	27	39	66
APP	-6+9	50	40	14	54	19	14	24	38
		100	44	17	61	22	20	31	51
		200	47	18	65	24	26	43	69
Gafsa PR	-200	50	38	13	51	18	15	22	37
		100	42	13	55	20	17	25	42
		200	46	18	64	23	18	35	53
N. C. PR	-200	50	38	13	51	17	13	23	36
		100	43	16	59	23	15	29	44
		200	46	16	62	24	21	30	51
Florida PR	-200	50	35	9	44	12	14	17	31
		100	35	10	45	14	14	19	33
		200	38	12	50	16	14	24	38
Morocco PR	-200	50	34	6	40	12	15	15	30
		100	36	8	44	12	15	18	33
		200	37	11	48	14	15	19	34
Togo PR	-200	50	32	6	38	12	16	15	31
		100	35	8	43	12	15	17	32
		200	33	12	45	13	12	22	34
Quebec PR	-200	50	31	7	38	12	14	16	30
		100	31	7	38	12	13	17	30
		200	32	6	38	12	16	16	32
No P		0	30	6	36	12	14	14	28
LSD, 5% Level			4	4	4	3	4	6	5

Table 2. Mean yields of dry matter and uptake of P by rice.

P Source and Mesh Size	Yield of Dry Matter, g/pot			Grain Yield, % of Total	P Uptake, mg/pot			P in Grain, % of Total
	Straw	Grain	Total*		Straw	Grain	Total*	
CSP, -35	42.9	13.5	56.4b	24	19.6	27.1	46.7b	58
CSP, -6+9	43.9	15.8	59.7a	26	19.1	31.4	50.5a	62
SC-CSP, -6+9	34.7	5.9	40.6d	15	18.0	15.0	33.0c	45
MAP, -6+9	42.8	16.9	59.7a	28	20.9	32.5	53.4a	61
APP, -6+9	43.4	16.3	59.7a	27	19.9	32.5	52.4a	62
Gafsa PR, -200	42.1	14.7	56.8b	26	16.6	27.3	43.9b	62
N. C. PR, -200	42.3	14.9	57.2b	26	16.6	27.3	43.9b	62
Fla. PR, -200	36.2	10.1	46.3c	22	14.0	20.1	34.1c	59
Morocco PR, -200	35.6	8.3	43.9d	19	15.3	17.1	32.4c	53
Togo PR, -200	33.6	8.6	42.2d	20	14.2	17.8	32.0c	55
Quebec PR, -200	31.4	6.8	38.2e	18	14.3	16.0	30.3cd	53
No P	30.3	6.3	36.6e	17	13.7	14.4	28.1d	51
LSD, 5% Level	2.2	2.3	2.4	-	2.4	3.8	2.9	-

*Total yields and P uptake followed by the same letter are not significantly different at the 5% level.

APPENDIX B

Preliminary TVA Data - Not for Publication

Report on Muscle Shoals Greenhouse Experiment 219-C:

RESPONSE OF FLOODED RICE TO P IN ROCK PHOSPHATES VARYING IN CITRATE SOLUBILITY

O. P. Engelstad and S. E. Allen

August 1970

SUMMARY

A series of rock phosphates varying rather widely in citrate solubility was compared with fine and granular concentrated superphosphate (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 the Tennessee, Missouri, and Indian (Udaipur deposit) rocks were almost completely ineffective.

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

BACKGROUND AND OBJECTIVE

The more reactive "soft" rock phosphates have been used with apparent success as sources of P for rice in countries where soils are rather acidic in reaction. These sources are lower in price than acidulated phosphates and are therefore of substantial interest as a means of reducing fertilizer cost. This is important where the price of fertilizer is quite high relative to that for rice.

In connection with the TVA-AID project, "Tailoring of Fertilizers for Rice," a series of rock phosphates varying in citrate solubility was collected in quantity and characterized by TVA. This series was used as a uniform supply for a number of field experiments on flooded rice in developing countries.

The objective of this experiment was to determine the effectiveness of this series of rock phosphates for flooded rice under our rather standardized greenhouse conditions; the data obtained will be compared with those from field experiments in developing countries.

PROCEDURE

Samples of rock phosphates were obtained from the same lots for which laboratory analyses are reported by J. R. Lehr in the June 1969 progress report of the Fundamental Research Branch. Identifying codes and citrate solubility levels are listed in Table 1. Fine (-35 mesh) and granular (-6+9 mesh) CSP were the standard sources.

Quantities of these materials sufficient to supply 50, 100, and 200 mg of P were mixed with 5 kg lots of Mountview silt loam and the whole placed in plastic pots. Three replicates of each treatment (including no P) were provided.

Previous uniform soil treatments were mixed as follows per pot (5 kg of soil): 3 g of a 2:1 mixture of $CaCO_3$ and $MgCO_3$, 300 mg of K as KCl, 200 mg of N as $(NH_4)_2SO_4$, and 300 mg of complete micronutrient mixture.

Nato rice was seeded directly at a rate of 22 seeds per pot on September 18, 1969; the soil was then brought to 22% moisture. Seedlings were thinned to 12 after emergence. Floodwater was applied at 3 weeks after seeding and maintained continuously throughout the growth period. Additional N was topdressed in 3 successive increments of 200 mg each as urea in solution. The first crop was harvested at boot stage on January 8, 1970.

The soil was allowed to dry out, then was processed through a 1/2-inch screen and returned to the pots. The second crop was planted on February 18. The seeding, thinning and flooding techniques followed were the same as for the first crop. Supplementary nutrients applied were as follows on a per-pot basis: 400 mg of K as KCl and 400 mg of N as $(NH_4)_2SO_4$ at planting.

N was topdressed in 2 increments of 200 mg each as urea in solution. The second crop was harvested at boot stage on May 21, 1970. All samples were dried, weighed, ground and analyzed for P content.

RESULTS AND DISCUSSION

The dry matter yields and P uptake data for the two crops are shown in Table 2 and Figures 1 and 2. Marked differences in effectiveness were obtained among P sources. Using both yield of dry matter and P uptake, the effectiveness of the various sources was calculated relative to granular CSP (Table 3). For the first crop, North Carolina rock was about 84% as effective as granular CSP based on dry matter and 90% based on P uptake. There were 3 groups of sources that formed a similar pattern for both crops. They are indicated by underlining in the following series:

$$\underline{CSP_g = CSP_f > NC} > \underline{N.\ Fla \gtrsim C.\ Fla \gtrsim Idaho} > \underline{Tenn \gtrsim Mo = India}$$

Response patterns and yield levels followed the same trend for both crops; there was good residual effectiveness for the more soluble sources.

Similar conclusions would be made using either dry matter yield or P uptake. Plotting yield vs uptake showed no appreciable differences in "efficiency" among P sources in terms of dry matter per unit of absorbed P.

There was a rather obvious relationship between citrate solubility of the rock phosphates and effectiveness (Figure 3). The simple correlation coefficient is 0.90, indicating that over 80% of the variation in average yield can be explained by variation in citrate solubility.

Table 1. Sources of rock phosphates, their TVA codes and citrate solubility.

Source	TVA Codes		Citrate Solubility % of Total P
	Fundamental Research Branch	Process Engineering	
Central Florida	MR-464	PR-2	16.2
Idaho	MR-465	PR-1	11.5
North Florida	MR-466	PR-4	20.4
North Carolina	MR-467	PR-3	26.1
Tennessee	MR-468	PR-5	14.9
India	MR-469	--	5.2
Missouri	MR-505	PR-6	1.4

Table 2. Dry matter yield of rice and P uptake, as affected by source and rate of P.

Source of P	Rate of P mg/pot	Yield of Dry Matter, g/pot			Uptake of P, mg/pot		
		Crop 1	Crop 2	Total	Crop 1	Crop 2	Total
Central Florida	50	21.4	18.0	39.4	24.0	14.7	38.7
	100	25.9	22.7	48.6	29.7	18.0	47.7
	200	31.5	29.2	60.7	36.6	22.0	58.6
Idaho	50	20.5	18.0	38.5	23.8	12.2	36.0
	100	23.4	25.4	48.8	28.0	18.1	46.1
	200	24.8	29.7	54.5	30.9	25.3	56.2
North Florida	50	23.0	22.6	45.6	29.1	18.0	47.1
	100	27.2	22.9	50.1	31.1	16.0	47.1
	200	35.0	32.8	67.8	33.4	27.0	60.4
North Carolina	50	31.1	25.8	56.9	34.7	21.7	56.4
	100	40.5	35.6	76.1	44.4	29.4	73.8
	200	42.4	46.7	89.1	51.2	46.8	98.0
Tennessee	50	18.4	17.5	35.9	22.1	13.8	35.9
	100	17.9	15.6	33.5	23.8	11.2	35.0
	200	18.7	16.8	35.5	21.5	12.1	33.6
India	50	14.1	15.0	29.1	14.2	11.3	25.5
	100	16.0	16.2	32.2	19.0	13.3	32.3
	200	15.9	16.0	31.9	17.4	10.9	28.3
Missouri	50	16.7	15.4	32.1	17.4	11.6	29.0
	100	16.6	17.3	33.9	18.2	13.9	32.1
	200	17.2	20.3	37.5	19.6	14.7	34.3
CSP (-35 mesh)	50	38.1	28.8	66.9	43.5	24.3	67.8
	100	41.5	34.1	75.6	44.6	30.1	74.7
	200	43.1	47.0	90.1	56.2	47.7	103.9
CSP (-6+9 mesh)	50	39.1	25.5	64.6	40.0	20.0	60.0
	100	42.2	39.3	81.5	40.3	33.4	73.7
	200	44.6	50.2	94.8	57.2	45.8	103.0
No P	0	16.9	14.1	31.0	18.9	9.8	28.7

Table 3. Relative effectiveness of various phosphates over 2 consecutive crops.[1]

Source of P	Yield of Dry Matter		Uptake of P	
	Crop 1	Crop 2	Crop 1	Crop 2
Central Florida	37	37	42	31
Idaho	24	41	32	32
North Florida	46	48	46	39
North Carolina	84	87	91	85
Tennessee	6	10	13	10
India	0	6	0	7
Missouri	0	14	0	13
CSP (-35 mesh)	96	90	109	90
CSP (-6+9 mesh)	100	96	100	87

1/ These were calculated by averaging the dry matter yields and P uptake data over rates and replicates, subtracting the respective control, and dividing by the first crop value for granular CSP.

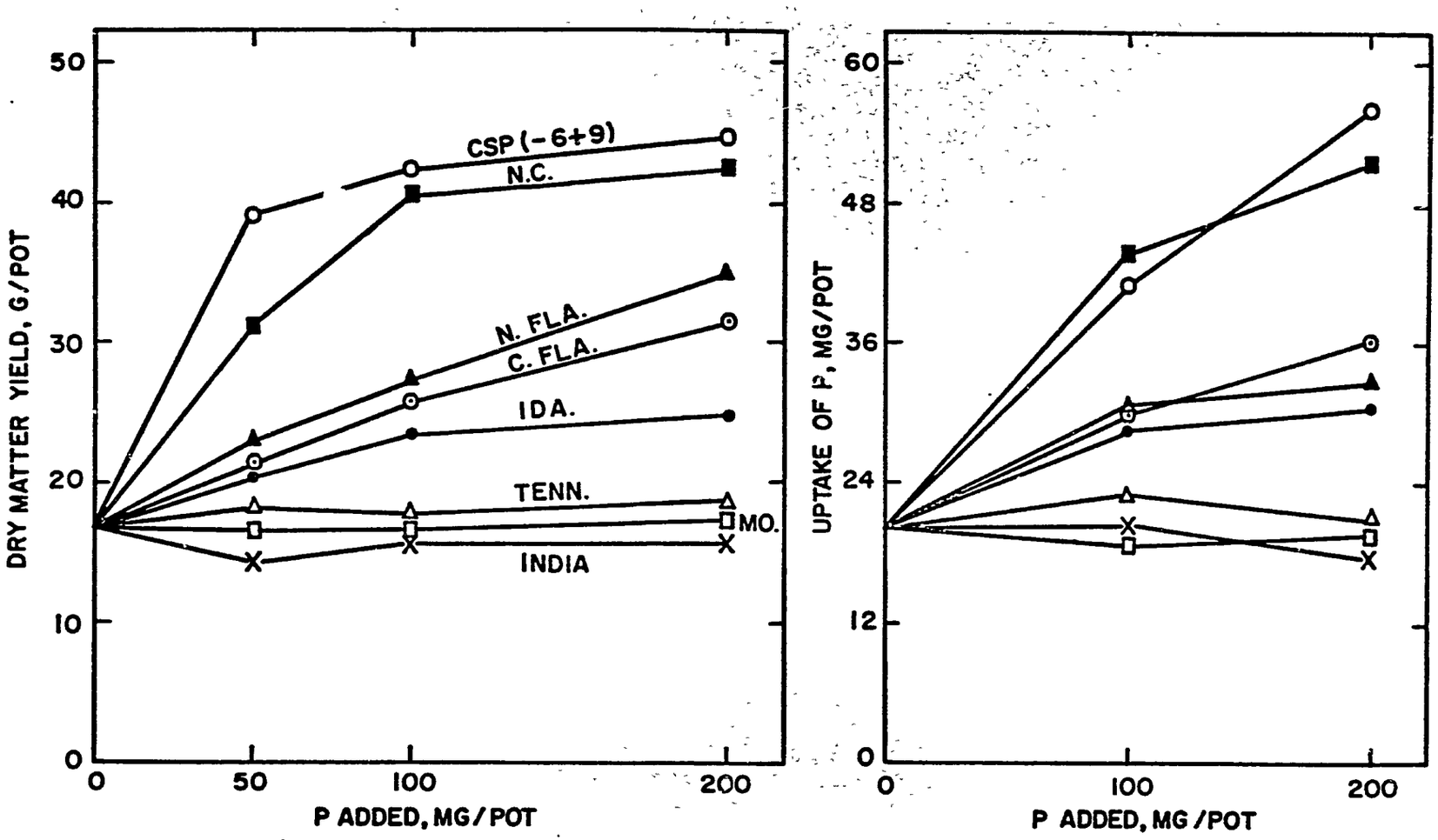

Figure 1. Dry matter yield and P uptake by first-crop rice, as affected by source and rate of P.

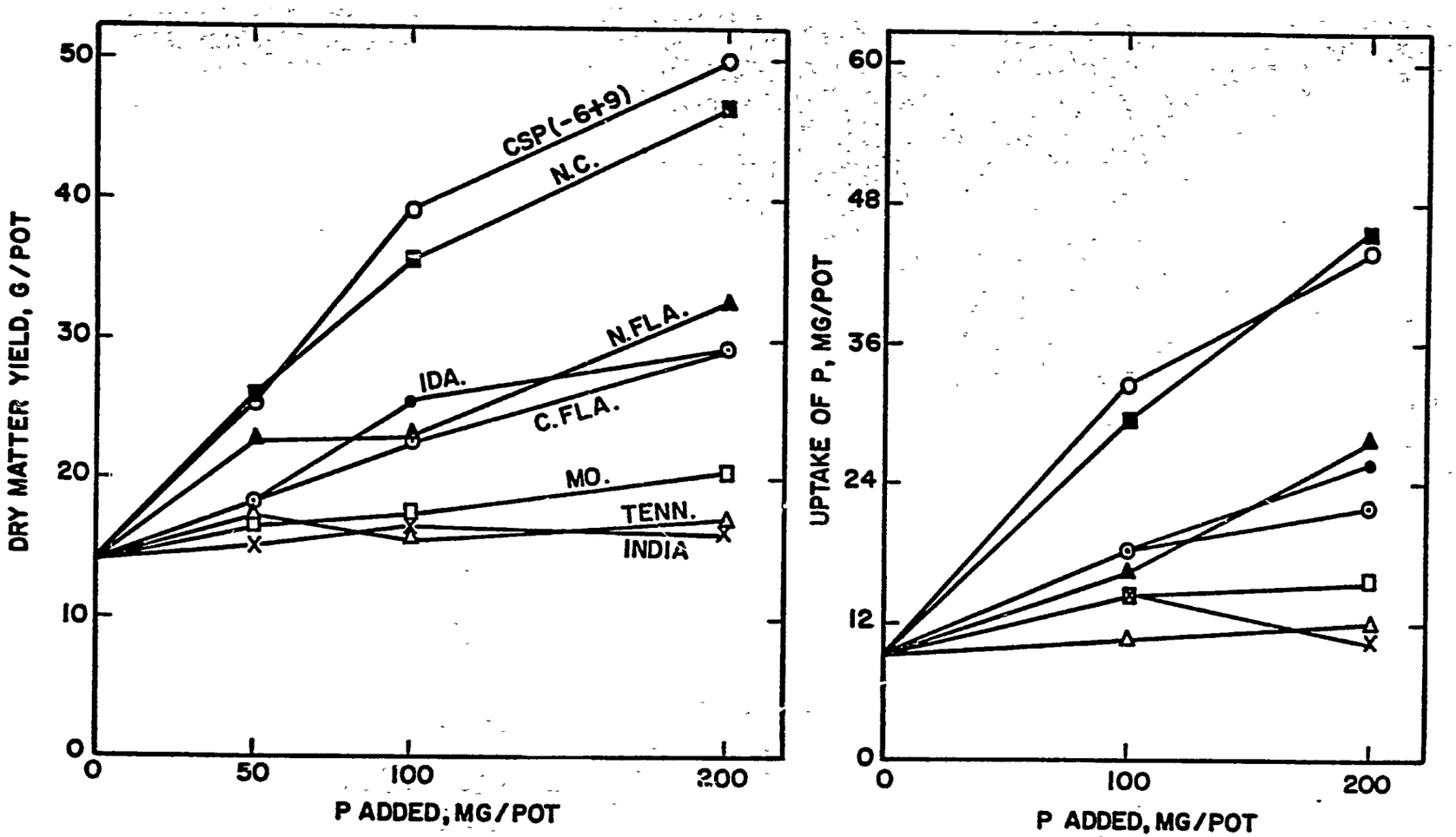

Figure 2. Dry matter yield and P uptake by second-crop rice, as affected by source and rate of P applied to the first crop.

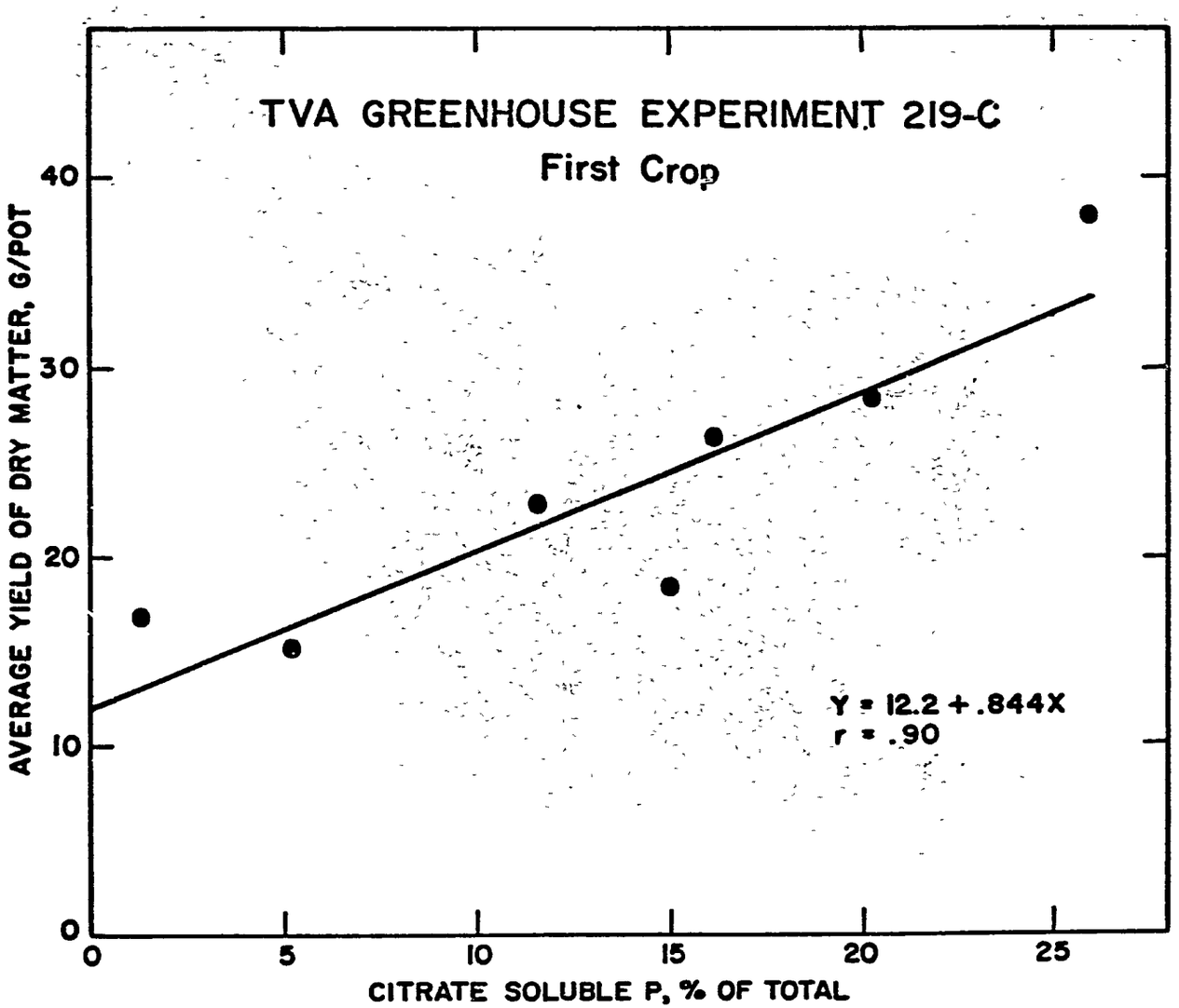

Figure 3. Corresponding yield of dry matter (averaged over rates and replicates) plotted against citrate solubility level of the rock phosphates.