AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON D C 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
0199

1 SUBJECT CLASSIFICATION

A PRIMARY
Agriculture AF25-0000-0000

B SECONDARY
Soil fertility,fertilizers,and plant nutrition--Cereals--Rice

2 TITLE AND SUBTITLE
Responce by flooded rice to phosphate rocks varying in citrate solubility

3 AUTHOR(S)
Engelstad,O P , Jugsujinda,Aroon, DeDatta,S K.

4 DOCUMENT DATE	5 NUMBER OF PAGES	6 ARC NUMBER
1974	7p.	ARC

7 REFERENCE ORGANIZATION NAME AND ADDRESS
TVA

8 SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(In Soil Science Soc.of Am.,Proc.,v.38,p.524-529)

9 ABSTRACT

10 CONTROL NUMBER
PN-RAA- 148

11 PRICE OF DOCUMENT

12 DESCRIPTORS
Citrates
Field tests
Phosphorus
Rice

13 PROJECT NUMBER

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

15 TYPE OF DOCUMENT

AID 590 1 (4 74)

10

Reprinted from the *Soil Science Society of America Proceedings*
Volume 38, no 3, May June 1974
677 South Segoe Rd Madison, Wis 53711 USA

Response by Flooded Rice to Phosphate Rocks Varying in Citrate Solubility

O P ENGELSTAD, AROON JUGSUJINDA, AND S K DE DATTA

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

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

ABSTRACT

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

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

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

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

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

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

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

Using a series of phosphate rocks varying in citrate solu

[1] Contribution from Soils and Fertilizer Research Branch National Fertilizer Development Center Tennessee Valley Authority Muscle Shoals AL 35660 This research was conducted jointly by TVA the International Rice Research Institute the Rice Department Thailand and was supported in part under an AID Participating Agency Service Agreement No RA(QA) 5 69 Received 25 Oct 1973 Approved 8 Feb 1974

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

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

Deposit	Description		Total P %	Citrate soluble P (% of total P)	Absolute citrate solubility index	CO_2 content of apatite †	Percent 100 (Tyler mesh)
North Carolina	Clastic phosphorite	(Sedimentary)	13 1	26 1	19 8	5 0	98
Florida (north)		(Sedimentary)	14 2	20 4	14 8	3 7	76
Florida (central)	Pebble	(Sedimentary)	14 3	16 2	10 1	3 5	96
Idaho	Shale phosphorite	(Sedimentary)	14 1	11 5	5 5	1 8	99
Tennessee	Brown rock	(Sedimentary)	13 4	14 7	1	1 5	78
India (Udaipur)		(Metamorphic)	17 5	5 2	1 7	0 7	89
Missouri		(Igneous)	15 2	1 4	1 2	0 2	98

Analytical data from June 1969 Progress Report of Fundamental Research Branch TVA The AOAC procedure was used in the determination of citrate soluble P
† Determined by chemical analysis

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

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

EXPERIMENTS CONDUCTED AND RESULTS

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

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

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

The ACS values are useful when comparing phosphate rocks of varying apatite content The CO_3 substitution in the apatite structure is indicated by the CO_2 content, which varied between 0 2 and 5 0% The percentage of each phosphate rock passing through a 100 mesh screen is also shown (varying between 76 and 99%) Further information on these phosphate rocks is provided by Lehr and McClellan

Greenhou Experiment

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

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

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

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

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

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

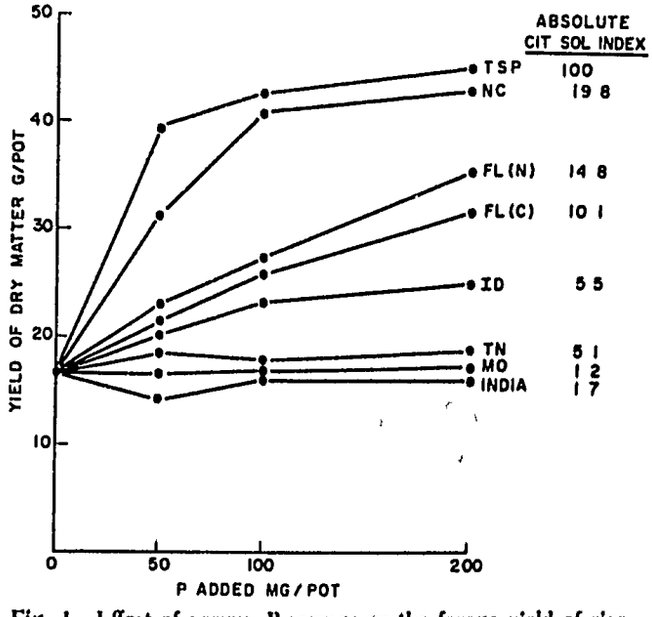

Fig 1—Effect of various P sources on the forage yield of rice in a greenhouse experiment (TVA)

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

Source of P	Crop 1	Crop 2
North Carolina	84	87
Florida (north)	46	48
Florida (central)	37	37
Idaho	24	41
Tennessee	6	10
India (Udaipur)	0	6
Missouri	0	14
TSP (35 mesh)	86	90
TSP (649 mesh)	100	96

*After averaging the dry matter yields over all rates these values were calculated using the formula $\frac{Y_{exp\ control}}{Y_{TSP\ control}} \times 100$

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

Field Experiments

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

Klong Luang Rice Experiment Station The soil was developed from brackish water sediments It possesses a heavy clay texture throughout the profile with a black upper horizon This is an acid sulfate soil, belonging to the Ongkarak series The pH of the plow layer of the experimental site was about 4 6

Bangkhen Rice Experiment Station The Bangkhen soil was derived from alluvial sediments, having a heavy clay texture throughout the profile At the experimental site, the pH of the plow layer was about 5 8

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

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

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

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

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

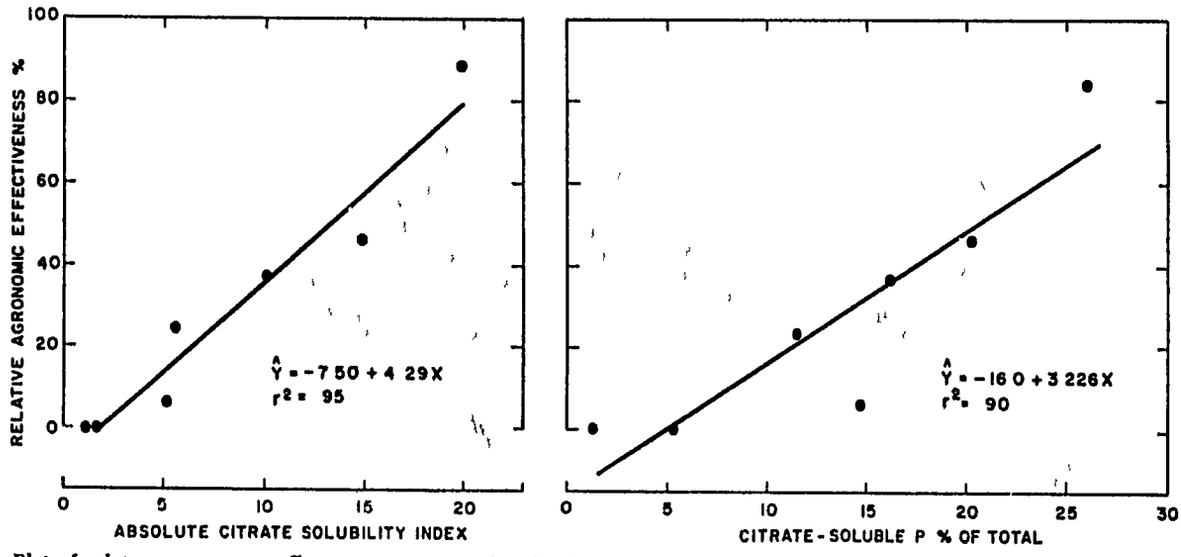

Fig 2—Plot of relative agronomic effectiveness against the absolute citrate solubility index and against the content of citrate soluble P, % of total (greenhouse experiment)

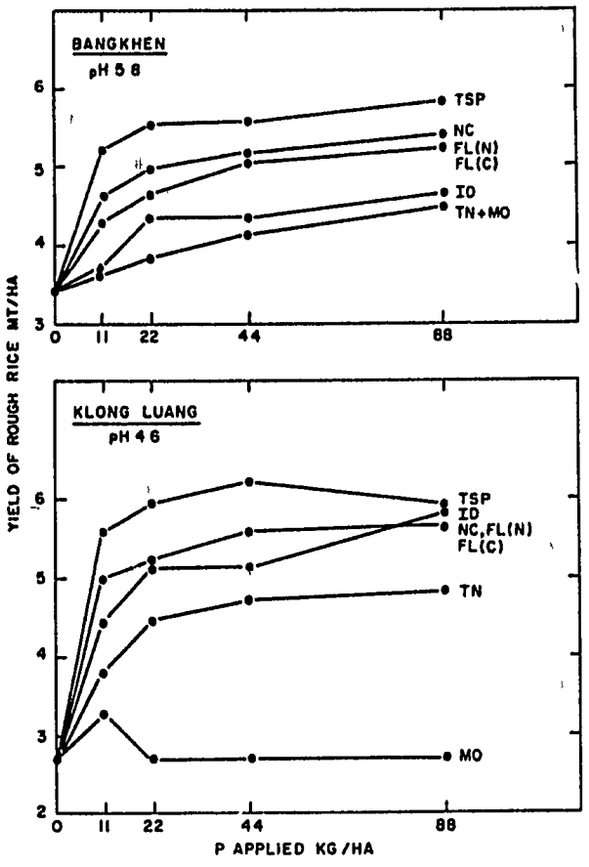

Fig 3—Yield of rough rice at Klong Luang and Bangkhen Rice Experiment Stations, Thailand, as affected by rate and source of P applied (crop 1)

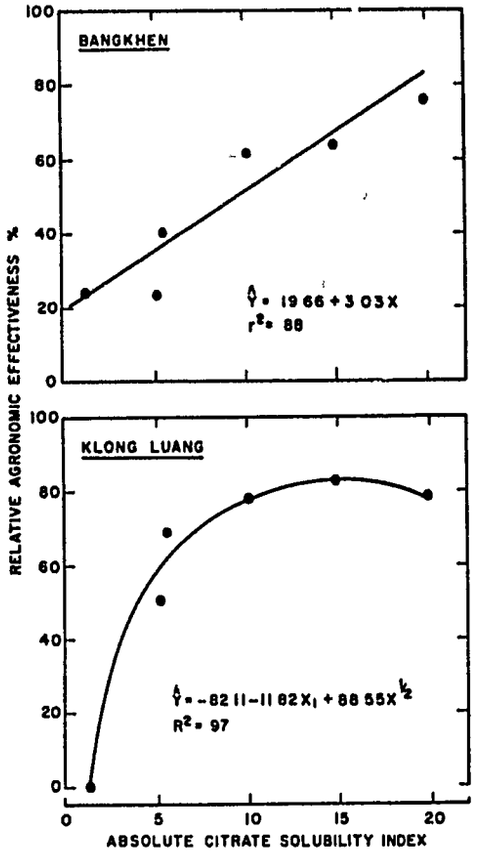

Fig 4—Relative agronomic effectiveness (%) of P sources plotted against citrate solubility index for both Thailand field experiments (first crop only)

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

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

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

Relative agronomic effectiveness values (Table 3) were calculated for the Klong Luang data using both the residual and freshly applied TSP as standards It is of interest to note that the superiority of TSP over the phosphate rocks persisted through the second crop The main difference in the residual effects is that with the exception of the Missouri rock the marked relationship between citrate soluble P content of the phosphate rocks and RAE had largely disappeared In this acidic soil (pH 4 6) P would by this time be supplied by intermediate reaction products in addition to residues of the initial apatite

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

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

DISCUSSION

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

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

Source	Klong Luang Crop 1	Klong Luang Crop 2†	Bangkhen Crop 1
North Carolina	78	59	76
Florida (north)	83	74	64
Florida (central)	78	69	6
Idaho	69	63	40
Tennessee	51	65	23
Missouri	0	0	24
TSP (crop 1)	100	94	100
TSP (crop 2)		100	

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

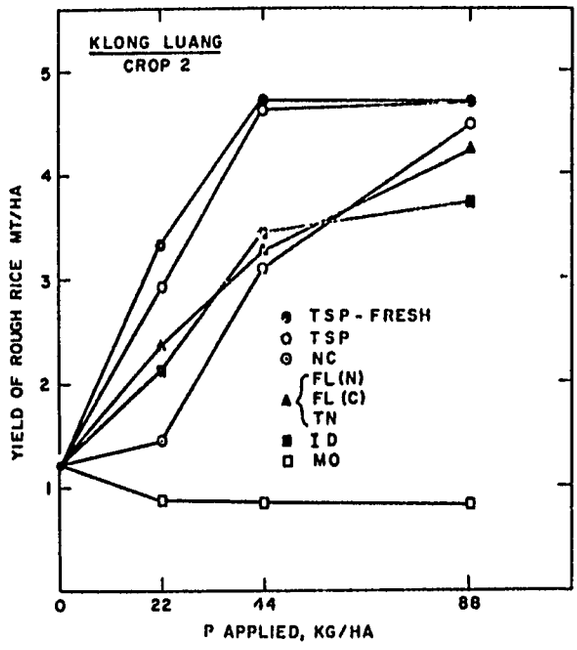

Fig 5—The residual effectiveness of various P sources for crop 2, as compared with freshly applied TSP Klong Luang Rice Experiment Station, Thailand

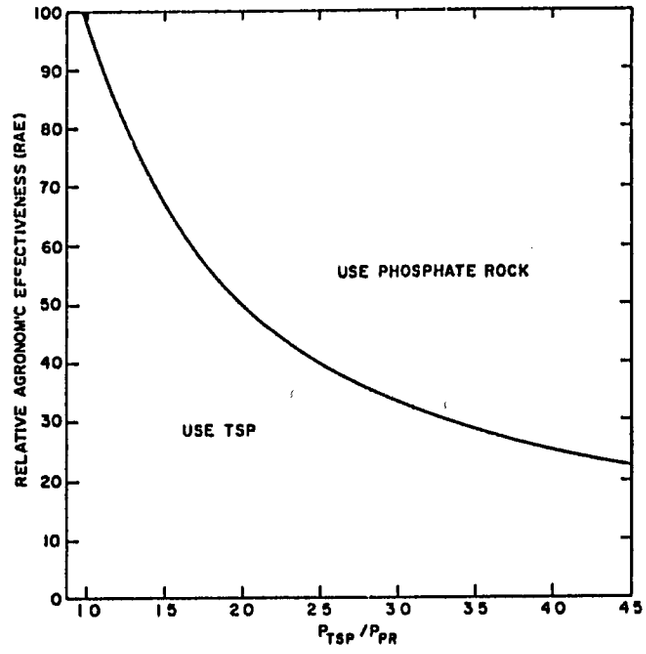

Fig 6—Relationship between relative effectiveness values (RAE) and the price ratios between TSP and phosphate rock Such a figure can be used in making a choice between these sources

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

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

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

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

or

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

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

The REE calculations were used in preparing an indifference curve (Fig 6) wherein RAE values are plotted against P_{TSP}/P_{PR} ratios The curve itself connects those points at which REE equals 100 When exactly on the curve, it makes no real economic difference what source is chosen After choosing a suitable price ratio, one can then project upward from that ratio, knowing the RAE value (or estimating it from such data as shown in Fig 4, using citrate soluble P content) one can then choose the source on the basis of both agronomic and economic considerations For example if the price ratio is 2 5 and the RAE value of the phosphate rock is greater than 40, the rock phosphate in question would be used However if the RAE value was less than 40, TSP would be a better choice There are indications that if the P in the more soluble phosphate rocks (North Carolina, north Florida central Florida) is less than half as expensive as that in TSP these rocks would be feasible alternatives to TSP on soils similar to those used in Thailand

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

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

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

LITERATURE CITED

1 Armiger, W H and Maurice Fried 1957 The plant availability of various sources of phosphate rock Soil Sci Soc Amer Proc 21 183–188

2 Bengston G W E C Sample and S E Allen 1974 Response of slash pine seedlings to P sources of varying citrate solubility Plant Soil (In press)

3 Caro J H and W I Hill 1956 Characteristics and fertilizer value of phosphate rock from different fields J Agr Food Chem 4 684–687

4 Ensminger L F R W Pearson and W H Armiger 1967 Effectiveness of rock phosphate as a source of phosphorus for plants US Dep Agr ARS Bull 41 125

5 Engelstad O P J G Getsinger and P J Stangel 1972 Tailoring of fertilizers for rice Tennessee Valley Authority National Fertilizer Development Center Bull Y 52

6 Khasawneh F E and Jane P Copeland 1973 Cotton root growth and uptake of nutrients relation of phosphorus uptake to quantity intensity and buffering capacity Soil Sci Soc Amer Proc 37 250–254

7 Lehr J R and G H McClellan 1972 A revised laboratory reactivity scale for evaluating phosphate rocks for direct application Tennessee Valley Authority National Fertilizer Development Center Bull Y 43

8 Termin G L S E Allen and O P Engelstad 1970 Response by paddy rice to rates and sources of applied phosphorus Agron J 63 390–394