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Response by Paddy Rice to Rates and Sources of Applied Phosphorus[1]

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ABSTRACT

A series of greenhouse pot experiments with flooded rice (*Oryza sativa* L. var 'Nato') was conducted on Mountview silt loam, a soil found to be very low in available P for upland crops Marked yield response by rice was obtained to applied P, but maximum yields were obtained at much lower rates of applied P than is true for most upland crops Response to applied P decreased with liming of the soil and with increasing levels of acid-soluble soil P Granular water soluble P sources were most effective for increasing tillering and yields of rice, granular dicalcium phosphate was inef fective Effectiveness of several fine phosphate rock sources increased with increase in content of AOAC-available P The P in S-coated concentrated super phosphate was not available to a first crop of rice but after degradation of the coating became available for a second crop The P in Fe phosphates was more avail able than that in Al phosphates in the flooded soil These phosphates were more available as fines than as granules and in colloidal form than as fine crystals

Additional key words Phosphate rock, Superphosphate, Ammonium phosphates, Fe and Al phosphates

MUCH of the world rice (*Oryza sativa* L) production is on soils showing low to moderate yield responses to applied P fertilizers Widespread use of rather fertile alluvial soils for paddy rice is one reason for this A second may be the accumulation of crop and fertilizer residues over long periods of cropping A third involves the reducing conditions which develop in flooded soils Iron phosphates in part cular, which have rather low availabi ty under well aerated conditions, may be reduced in flooded soils and become available to the rice crop Another reason for low response of rice to P in Asia and other areas where rice is transplanted is that the plants may be initially high in P as a result of heavy fertilizations of the nursery beds For these reasons, P fertilizers varying widely in availability to upland crops may all supply adequate P for rice under conditions of low response to applied P

Very few results from comprehensive P source and rate experiments on severely P deficient soil have been reported Most results from P source experiments are not very meaningful because of little or no response to applied P or because of high variability of the results The purpose of this paper is to report results of greenhouse pot experiments comparing various P rates and sources for paddy rice grown on soil extremely deficient in available P for upland crops

Since it was not possible to find soils used for rice production which were very low in available P, the soil selected was not one in which rice had been grown previously Consequently, the results obtained are perhaps not typical of most rice soils, but do provide information on P response characteristics of rice on soil which supplies only a small fraction of the crop needs

MATERIALS AND METHODS

Certain chemical components of the P sources compared in the various experiments are shown in Table 1 The Nato variety of rice was grown on Mountview silt loam (pH 5 0 5 kg per pot) in all experiments This soil tested very low in dilute acid soluble P The soil was limed to pH 6 3 with 6 25 g of a 2 to 1 mixture of $CaCO_3$ and $MgCO_3$ for all pots in Experiment 1 with 10 g of this mixture for half of the pots in Experiment 2 and 4 g for each pot in Experiment 3 Adequate amounts of N as urea or $(NH_4)_2SO_4$ (total of 600 mg of N/pot) K as K_2SO_4 (200 mg of K/pot) and micronutrients for good growth were also mixed with the soil for each experiment Each P or no P treatment was replicated 3 or 4 times

In Experimest 1 rice seed were planted by barely covering with soil and the plants thinned to 10 per pot The soil was maintained at 100% saturation for 3 weeks then flooded to a depth of 5 cm After 8 weeks of growth including a final 2 week drying period two replicates of the treatments were harvested at the boot stage An additional 300 mg of N per pot was added to the remaining 2 replicates which were then reflooded The final harvest of mature grain and straw was made 17 weeks after planting

In subsequent experiments rice seedlings were grown in sand cultures to a height of about 15 cm before transplanting to flooded soil Four hills of three plants each per pot were transplanted A continuous flood of 5 cm of water was maintained until harvest

Yields of dry foliage or of mature grain and straw and total content of P by a vanadomolybdate colorimetric method were determined for each pot Counts of stems per pot were made at time of harvest

EXPERIMENTS CONDUCTED AND RESULTS

Experiment 1

The Florida phosphate rock (PR), partially acidulated with H_3PO_4, and concentrated superphosphate (CSP) sources compared in Experiment 1 were the same as those previously evaluated for corn (Terman and Allen, 1967) Ammonium polyphosphate (APP), diammonium phosphate (DAP), monoammonium phosphate MAP), and urea ammonium phosphate (UAP)

Table 1 Certain chemical components of the P sources,

	Total N %	Total P %	% of total P AOAC avail	% of total P Water sol	Exp
Florida phosphate rock (PR)		13 8	12	0	1
PR 10% acidulation		15 8	37	22	1
PR 25% acidulation	-	17 6	59	45	1
PR 50% acidulation	-	20 2	83	71	1
PR 75% acidulation	-	21 6	94	86	1
100 % (conc superphos CSP)		22 9	99	93	1 5
Ammonium polyphosphate (APP)	15 2	27 4	100	100	1, 4
Diammonium phosphate (DAP)	21 2	23 5	100	100	1
Monoammonium phosphate (MAP)	12 2	26 9	100	100	1, 4
Urea ammonium phosphate (UAP)	24 7	16 3	100	100	1
Gafsa I R	-	12 -	21		4
North Carolina PR	-	13 1	24	-	4
Florida PR	--	14 3	15	-	4
Morocco I R		16 0	11	-	4
Togo PR	--	16 0	9	-	4
Quebec I R		17 7	6	-	4
Sulfur coated CSP	--	14 8	-	-	4
Nitric phosphate (NP) 1	20 0	9 3	100	54	5
(NP) 2	19 6	8 7	100	23	5
Dicalcium phosphate (DCP)		22 7	100	3	5
Colloidal $AlPO_4$	-	15 1	-	-	5
Colloidal $FePO_4$	-	14 5		-	5
Variscite ($AlPO_4$ $2H_2O$)		19 2	-	-	5
Strengite ($FePO_4$ $2H_2O$)		16 8	-	-	5
$MgNH_4PO_4$ H_2O	8 9	20 0	93	-	5
$FeNH_4PO_4$ H_2O	7 2	16 4	97		5
$ZnNH_4PO_4$	7 8	17 4	48	-	5

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were also included All were granular fertilizers (—6+9 mesh), except for the —200 mesh Florida PR Each source was mixed with the soil to supply 20, 40, and 80 ppm (100, 200, and 400 mg of P/Pot) Rice seeds were planted in March 1967

Figure 1 shows yield response by rice to 20, 40, and 80 ppm of P after 8 and 17 weeks of growth There was only slight response to CSP above 20 ppm of P The same was true for the ammonium phosphates and variously acidulated PR fertilizers (data not shown) Consequently, it was not possible to evaluate these sources in this experiment, since all supplied near adequate P at all application rates

Response to unacidulated Florida PR was much lower than to the more soluble sources and increased up to 40 ppm of applied P Similar differences among P sources were found for crop uptake of P as were found for dry matter

Response of corn (*Zea mays*) to CSP and PR after 8 weeks' growth in a previous experiment on the same soil (Terman and Allen, 1967) increased in a near linear manner with all application rates This illustrates the commonly made observation that crops grown under nonflooded conditions usually respond much more to applied P than does paddy rice grown on the same soil (Kapp, 1948, Sturgis, 1936, Mitsui, 1964, Patrick and Mahapatra, 1968)

Experiment 2

Granular CSP was mixed with the unlimed and limed soil to supply 10 and 20 ppm of P/pot Rice was transplanted in November and harvested after 12 weeks as heads were starting to emerge in January 1969

As shown in Table 2, yield of dry foliage and uptake of P were increased significantly by liming without applied P With applied P, yield and uptake were much higher, but there was no appreciable effect of liming The pH of the flooded soil at harvest was 5 7 to 6 1 without liming and 6 6 to 6 7 with liming

Experiment 3

Mountview soil limed to pH 6 0 was moist incubated for 6 weeks with 0, 40, and 200 ppm of P as a 1 to 1 mixture of fine CSP and anhydrous dicalcium phosphate (DCP) These additions resulted in acid soluble P levels of very low, medium, and high

Granular CSP and a mixture of 50% CSP and 50% DCP were mixed with the variously phosphated soil to supply 0, 10, 20, and 40 ppm of P at time of transplanting rice seedlings in March 1969 After 7 weeks' growth the crop was harvested in May at the boot stage of head development

Marked responses (Table 3) were obtained to applied granular CSP on the low P soil, both in terms of yield of dry foliage and of tillering Much less response was obtained to the granular CSP DCP mixture Response to 40 ppm of applied P was barely significant at the 5% level on the soil medium in P No response to applied P was obtained on the soil high in soluble P

Experiment 4

In experiment 4 various 200 mesh PR sources from several countries (Table 1) were compared with granular (—6+9 mesh) APP, MAP, CSP, and sulfur coated CSP The coated CSP had a total coating weight of 33%, of which 3% was a wax sealant Only 0 4% of the P dissolved in water at 43 C in 1 day and 1 1% in 5 days Each source was mixed with the soil to supply 10, 20, and 40 ppm of P

Rice was transplanted June 26, 1968 and grain and straw were harvested on October 15, 16 weeks after transplanting Heads were still green when grown on soil receiving no applied P or the less soluble PR sources and the grain was poorly filled

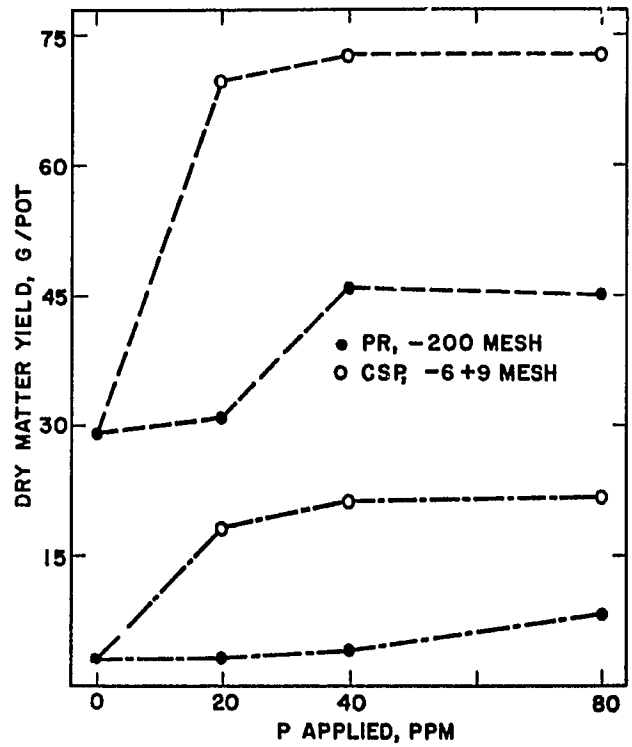

Fig 1 Yield response by rice to P in CSP and Florida PR on Mountview silt loam
Below — 8 weeks' growth
Above — 17 weeks' growth (Experiment 1)

Table 2 Effect of liming Mountview silt loam on response by rice to applied P (Experiment 2)

Liming	P applied ppm	Yield of dry foliage g/pot	P uptake mg/pot	No of plants and tillers/pot
Unlimed	0	9	12	10
	10	22	26	14
	20	25	31	16
Limed	0	13	15	13
	10	21	26	14
	20	25	33	16
LSD 5% level		2	3	3

Table 3 Response to P applied at transplanting by rice grown on Mountview silt loam at different levels of soluble P (Experiment 3)

P source and amount applied ppm	Yield of dry foliage g/pot			No of plants + tillers/pot		
	V low P	Med P	High P	V low P	Med P	High P
0	7	27	33	12	37	49
100% CSP						
10	18	29	33	28	39	46
20	25	32	32	33	40	46
40	31	33	31	39	43	43
50% CSP 50% DCP						
10	11	28	31	15	35	46
20	16	27	31	25	35	49
40	20	29	29	26	38	43
LSD 5% level	3	5	ns	5	5	ns

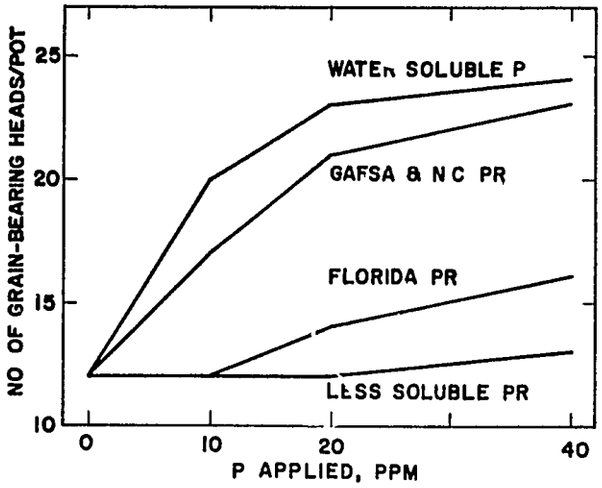

Fig 2 Effect of source and rate of applied P on number of grain bearing heads at harvest Water soluble P—APP,CSP, and MAP, less soluble PR—Morocco, Togo, and Quebec sources (Experiment 4)

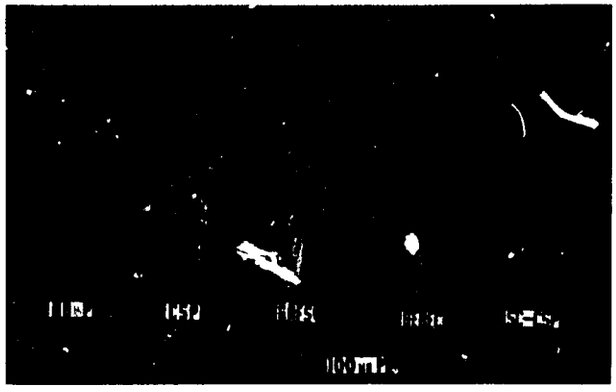

Fig 3 Grain development and tillering of rice with no applied P and with 100 mg of P (20 ppm) as CSP, S-coated CSP, Gafsa PR, and Quebec PR (Experiment 4)

After drying, roots and stubble from crop 1 were mixed with the soil A second crop was similarly grown on the soil of selected treatments with N and K additions but without additional applied P

Tillering Fig 2 shows that numbers of grain bearing heads at time of harvest increased with the 10, 20, and 40 ppm P rates of the water soluble sources (APP, MAP, and CSP) The same was true for Gafsa (Tunis) and North Carolina PR sources, for which there were fewer tillers The less reactive PR sources had only a slight effect on tillering at the higher P rates No tillers were formed with no applied P, Quebec PR, the least reactive source, and S coated CSP Differences in tillering and stage of grain development are shown in Fig 3 These results indicate that the higher P concentrations such as those found adjacent to granules or bands of water soluble P fertilizers (Terman, 1967) are essential for tillering and early grain development of rice in a soil very low in acid soluble P Similar effects have been reported for other small grains

Yield Response As shown in Fig 4, most of the grain yield response was obtained with 10 ppm of P applied as granular water soluble sources (APP, MAP, and CSP) which had similar effects Yields of grain

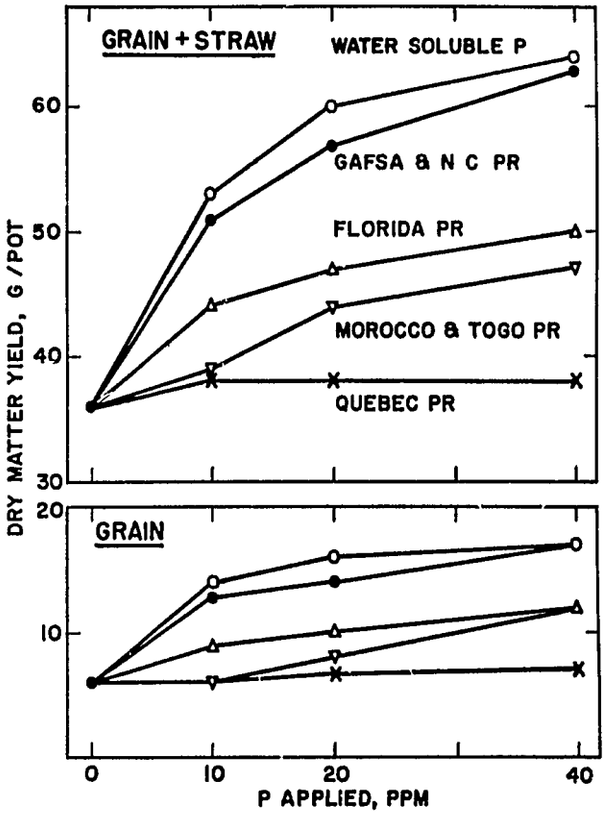

Fig 4 Yields of rice grain and of grain + straw as affected by source and rate of applied P (Experiment 4)

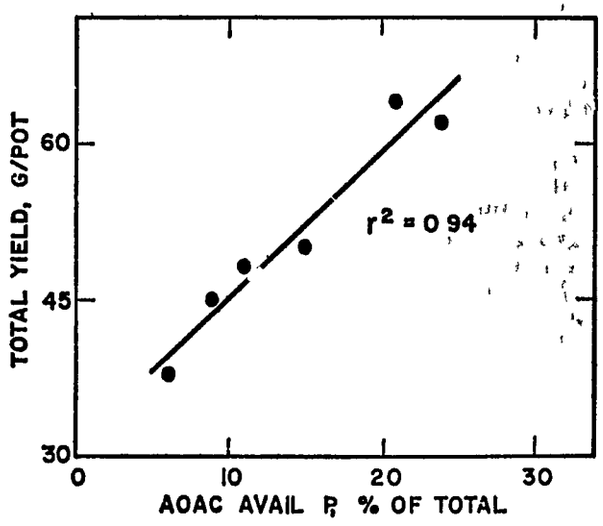

Fig 5 Relationship between total yield of grain and straw with 40 ppm of applied P and dissolution of PR sources in ammonium citrate (Experiment 4)

plus straw, however, increased with all rates of applied P Slightly less grain and total yield were obtained with the Gafsa and North Carolina PR than with the water soluble sources Similar conclusions could be drawn from comparisons of uptake of P by the rice crop

Response to P in the various PR sources was closely related (Fig 5) to their solubility in ammonium

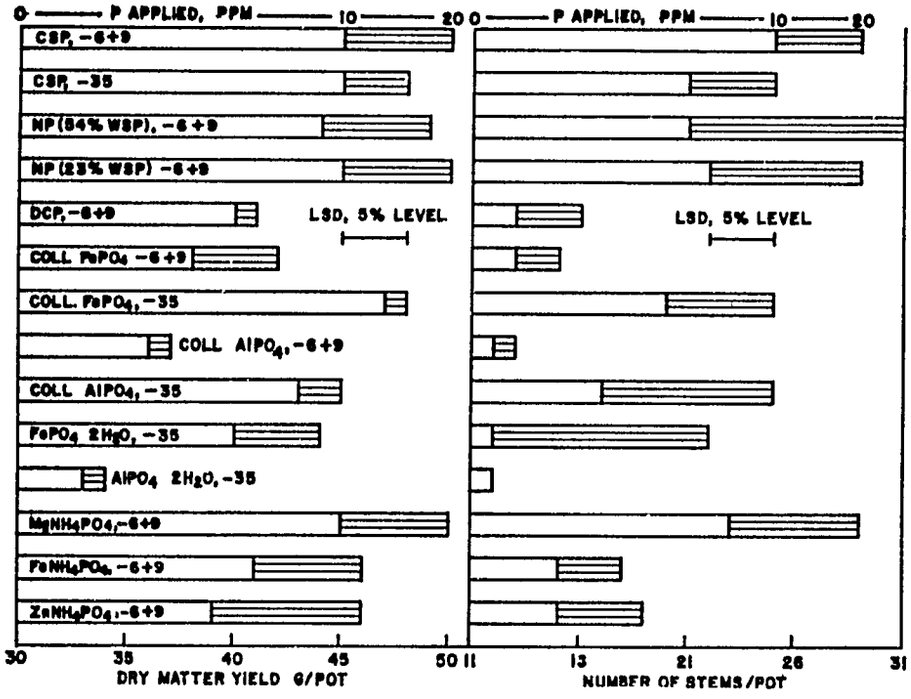

Fig 6 Dry matter yields and tillering of rice, as affected by P source, rate, and granule size (Experiment 5)

citrate solution (AOAC method) This result may help to explain some of the differences in conclusions in the literature concerning the relative value of PR and more soluble phosphate fertilizers for rice The agronomic value of a particular PR source varies widely with its fineness and reactivity, which is different among geographical sources and even within the same source (Caro and Hill, 1956) Lehr (1967) found that reactivity of phosphate rocks was rather closely related to the degree of substitution of Ca, P, and F in the apatite structure by other elements

Growth of crop 2 with P residues from crop 1 were in the order S coated CSP > CSP > Gafsa PR > Florida PR Except for S coated CSP, the order of response was the same for both crops Thus, the relative residual availability for CSP and the phosphate rocks was the same as for the freshly applied P sources The S coating prevented appreciable release of P from CSP for crop 1, but S coated CSP was the most effective source for crop 2, due apparently to degradation of the coating and release of P for crop 2

Experiment 5

In experiment 6, several granular (—6+9 mesh) fertilizers were compared (Table 1) These were CSP, two nitric phosphates (NP, 23 and 54% of the P water soluble), DCP, colloidal Al and Fe phosphates (Lindsay and DeMent, 1961), and Mg, Fe and Zn ammonium phosphates Finely crystalline strengite ($FePO_4$ $2H_2O$) and variscite ($AlPO_4$ $2H_2O$) were also included, as were fine CSP and fine colloidal Al and Fe phosphates Each source was mixed with the soil to supply 10 and 20 ppm of P Rice plants were transplanted in February and after 12 weeks' growth harvested at the early heading stage of grain development in May 1969

As shown in Fig 6, most of the yield response was obtained to 10 ppm of applied P from the various sources, with an additional significant response to 20 ppm from most sources Highest yields and P uptake were obtained with granular CSP, NP, $MgNH_4PO_4$, and fine colloidal $FePO_4$, and intermediate yields with granular $FeNH_4PO_4$, $ZnNH_4PO_4$, fine colloidal $AlPO_4$, and crystalline $FePO_4$ $2H_2O$ (strengite) Lowest yields and P uptake were obtained with fine crystalline $AlPO_4$ $2H_2O$ (variscite), granular DCP, and colloidal $FePO_4$ and $AlPO_4$ The crystalline strengite was much more available than variscite, apparently because of reduction of ferric Fe in strengite to form a soluble ferrous phosphate

Counts of the number of stems at harvest (Fig 6) indicated little or no tillering with fine crystalline variscite, granular DCP, colloidal $AlPO_4$, and colloidal $FePO_4$ The greatest tillering occurred with CSP and NP sources containing water soluble P or with $MgNH_4PO_4$ The pronounced dependence of yields on tillering in this experiment is indicated by the highly significant r^2 values of 0 66 and 0 74 at the 10 and 20 ppm applications of P Thus 66 and 74% of the variation in yields was related to tillering

Rather similar results were obtained by Shapiro (1958), who compared superphosphate with amorphous and crystalline Al and Fe phosphates as sources of P for rice grown on Chester loam (limed to pH 6 7) Growth and P uptake were higher with all sources in flooded than in unflooded soil However, flooding increased response to Fe phosphate much more than to Al phosphate The crystalline sources were much less available than those in amorphous form Patrick and Mahapatra (1968) have recently summarized the effects of flooding on transformations and availability of soil and fertilizer phosphates

CONCLUSIONS

Use of a soil very low in available P for these experiments made it possible to study the effects of various fertilizer properties on rice which have not been previously reported Thus, the marked effect of granular water soluble phosphates on tillering and yields was demonstrated in contrast to the poor results with granular DCP of low water solubility The marked differences in yields with PR sources varying widely in solubility help to explain the differences in results with PR reported by various investigators

The leveling off of the response of rice at low rates of applied P, even on a soil testing very low in soluble P, indicates the necessity of evaluating P fertilizers for rice at quite low application rates At application rates normal for upland crops, most P sources may all supply adequate P for rice Lower rates of applied P are thus needed on a given soil for high yields of paddy rice than are needed for upland grain crops The need for applied P was further reduced by liming the acid Mountview soil

The better results with Fe phosphates than with Al phosphates for rice emphasize the role of reduction reactions in flooded soils in making soil and fertilizer P more available than in comparable unflooded soils

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