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Phosphorus Availability of Some Philippine Rice Soils as Affected by Soil and Water Management Practices

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ABSTRACT

It is well established that flooding increases the availability of soil P to rice (*Oryza sativa* L.). Very little is known, however, on the influence of native soil P status or the type of water management used on the growth and P uptake of this crop. Also, the interaction between these two factors is unknown. In order to clarify these relationships, two greenhouse experiments were conducted on six representative Philippine lowland rice soils. The results indicate that the beneficial effects of flooding to rice vary with the level of available soil P, as measured by P uptake. In soils of high P availability, no differences were observed when rice was grown under constant flooding, on a partially oxidized profile or when flooding was delayed from 15 to 35 days after seeding. The latter two treatments produced lower yields and P uptake in comparison to constant flooding in soils of moderate to low P availability. When severe water stress occurred, rice growth, yield, and P uptake drastically decreased in all soils regardless of P availability. Puddling flooded soils has no effect on rice yields or P uptake at harvest regardless of soil P availability. Puddling unflooded soils severely decreased growth and responses to applied P when severe soil shrinkage took place. The benefits of flooding on P uptake by rice depend both on the available P level and the type of water management used.

Additional key phrases: **P uptake, Flooding, Water stress, Oxidation reduction potentials.**

AFTER water and nitrogen, phosphorus is probably the most critical soil parameter limiting lowland rice (*Oryza sativa* L.) production in Southeast Asia. The beneficial effects of flooding on P availability of the rice plant are well established for conditions of constant flooding (9). Increases in soil solution P upon flooding are often of such magnitude that rice fails to respond to P applications while other crops growing in the same soil but under aerobic conditions do respond (5, 9). Nevertheless, certain soils are known to be deficient in P even under these conditions.

More than 75% of Southeast Asia's lowland rice area does not have irrigation facilities (1). In such areas irregular rainfall may lead to water stress or alternate conditions of oxidation and reduction in the soil. Almost all lowland rice soils are puddled. The effect of soil puddling on P availability has not been established, although several reports suggest that this practice may increase P uptake by rice (6, 7, 8). Recently, a multiple cropping system has been proposed in which the central concept is to grow rice without puddling under several water management schemes (2). The soil may be flooded either immediately after planting or during the 5th week of growth. It may remain unflooded but with a water table kept near the topsoil-subsoil interphase. The purpose of this investigation is to evaluate the effect of the above-mentioned soil and water management practices on the growth, yield, and P uptake of rice.

PROCEDURE

Experiment 1

A pot experiment was conducted in an outdoor, unsheltered screenhouse adjacent to the Soils Department of the University of the Philippines at Los Baños. A factorial experiment of five soils and five management systems was used in a randomized complete block design with two replications. The soils chosen are representative of large lowland rice growing areas of Luzon. Maahas clay, an Andeptic Haploquoll derived from volcanic tuff, has a high available P content. Quingua clay, a Typic Tropaquept, represents the extensive soils derived from relatively young alluvium in the Central Plain of Luzon; it also has a high available P content. Buenavista clay, a Typic Ustropept, is representative of extensive terraced areas of the Central Plain where P deficiency has been reported. Faraon clay loam, a Typic Argioquoll, is derived from coralline limestone. Isarog silty clay, a Typic Dystrandept from the Bicol region, is poorly supplied with P. The properties of the five soils appear in Table 1. These soils were found to be adequately supplied with other nutrients except N or P (11).

Soils with granulated structure received the following management treatments: (1) irrigated after visible water stress; (2) water table fluctuating between 5 and 10 cm *below* the soil surface (1/3 to 2/3 of the pot depth); (3) flooded with water table fluctuating between 2 and 4 cm *above* the soil surface; (4) similar to (3) but flooding was delayed to 35 days after planting. Treatment (5) was similar to (3) except that the soils were puddled.

New 5-liter clay pots were painted with coal tar and filled with 4.5 kg of air dry soils previously subjected to several alternate wetting and drying cycles until a high degree of granulation was attained. The pots were then wetted to saturation from below. Treatment 5 was puddled by hand until a degree similar to field puddling was attained. Eight pregerminated rice seeds of the 'ponlai' PI-215936 cultivar were sown on the soil surface. The seedlings were thinned to four after 15 days. Heavy rainfall kept all pots flooded for the first 15 days, after which the water management differentials were established. Ammonium sulphate was added at the rates of 14 ppm N at planting, 14 ppm N at 29 days, and 112 ppm N at 43 days after planting. The aboveground plant parts were harvested at 27, 68, and 111 days after seeding. These dates corresponded to the tillering, panicle initiation, and maturity stages. Dry matter production was determined and reported as the equivalent of two plants per pot. Plant P was extracted by wet ashing and determined by the vanadomolybdate phosphoric acid method. The Bray No. 2 procedure was used to estimate available soil P because it is the most widely used soil test in the Philippines. The redox potentials were determined potentiometrically from percolates extracted in the presence of an N_2 atmosphere according to the procedure described by Ponnamperuma (10).

Table 1. Characteristics of the soils.

Soil type	pH	Bray no. 2 P	Organic matter	Exchangeable CEC	Exchangeable Ca	Exchangeable Mg	Exchangeable K
		ppm	%	meq/100 grams			
Maahas clay	5.7	11.6	2.85	34.9	19.4	5.9	1.8
Quingua clay	5.9	4.4	1.73	29.6	18.8	9.9	0.3
Faraon clay loam	7.0	18.6	4.24	44.5	33.8	4.8	0.6
Buenavista clay loam	5.7	3.2	1.67	20.3	13.6	3.4	0.3
Isarog silty clay							
A horizon	5.1	5.4	10.71	30.2	5.4	2.5	1.2
B horizon	5.5	0.0	2.70	31.1	2.5	2.7	1.2

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Experiment 2

Phosphorus-puddling interactions were studied during the dry season in an experiment conducted in 208.1-liter (55-gal) cylinders fitted with a water table measuring device. The P deficient Isarog soil was used with 15 cm of the A horizon over 40 cm of the B horizon. A 2 × 2 factorial design, composed of two topsoil physical conditions (puddled and granulated) and two P rates (0 and 100 ppm P), was arranged in a randomized complete block design with two replications. Ordinary superphosphate was banded at approximately 1 cm beside and 3 cm below the seeds. An application of 100 ppm N and K as urea and KCl was mixed in the topsoil prior to planting. The Hakkoda rice cultivar was seeded in a circle 30 cm in diameter. The water table was kept at 15 cm below the soil surface throughout growth and was adjusted daily by irrigation or drainage. Plant samples were collected at the tillering, panicle initiation, 50% flowering, and maturity stages.

RESULTS AND DISCUSSION

The dry matter production and P uptake by rice in the first experiment appear in Tables 2 and 3, respectively. Differences in grain yields, dry matter production, and P uptake among soils were statistically significant. The Maahas and Quingua soils showed the highest P-suppling capacity as measured by P contents and uptake. Rice growing on the Buenavista and Isarog soils showed extreme P deficiency symptoms after the 1st month of growth. Grain yields and total dry matter were decreased by half and the total P uptake to one fifth of that obtained with the Maahas and Quingua soils. Rice growth in the calcareous Faraon soil occupied an intermediate position with lower P uptake throughout growth but higher grain yields and total dry matter than in Maahas and Quingua. Differences in grain yields, dry matter production, and P uptake among management treatments were also statistically significant. The individual treatments are discussed separately in relation to the flooded-granulated as the base treatment.

Effects of Water Stress—Heavy rainfall during the 1st month precluded water stress in Treatment 1. No differences in P uptake or dry matter production were observed at this stage between Treatments 1, 2, and 3 (Tables 1 and 2). Growth, yield, and P uptake were drastically decreased by applying water stress. The treatments subjected to water stress produced 13% of the yields obtained in the flooded treatments. Water consumption by rice under water stress during the last 60 days of growth averaged 15% of that consumed by the flooded treatment and 22% of that consumed by Treatment 2.

Effects of a Partially Reduced Profile—Keeping a water table fluctuating between 5 and 10 cm below the soil surface (Treatment 2) kept the soils at higher redox potentials than in the flooded treatments (Table 4). No water stress symptoms were observed in Treatment 2. Water consumption by rice in this treatment averaged 67% of that consumed in the flooded pots. In the Maahas and Quingua soils no differences in dry matter production or gain yields were observed between Treatments 2 and 3, although P contents and uptake at 27 and 68 days were higher with flooding (Treatment 3). The P status of Treatment 2 in Maahas and Quingua soils seemed adequate throughout growth. In the Faraon soil the unflooded treatment produced significantly lower dry matter and P uptake than did flooding throughout crop growth. Significant differences between Treatments 2 and 3 in percent P were observed at the panicle initiation stage (0.19 vs 0.26%) and in the grain (0.17 vs 0.24%) at harvest. This may reflect a lower availability of P with the low water table due to higher

Table 2. Effects of soil and water management treatments on dry matter production at several growth stages and grain yields of rice.

Water management	Physical condition	Soils: Maahas	Quingua	Faraon	Buenavista	Isarog	Mean soils
		Dry matter production, g/pot					
		Tillering stage, 27 days					
1. Water stress	Granulated	0.51	0.55	0.30	0.18	0.15	0.34
2. W. table -5-10 cm	Granulated	0.56	0.56	0.35	0.17	0.13	0.35
3. Flooded	Granulated	0.50	0.43	0.28	0.18	0.15	0.31
4. Delayed flooding	Granulated	0.52	0.55	0.28	0.15	0.15	0.33
5. Flooded	Puddled	0.65	0.57	0.56	0.19	0.28	0.45
Mean		0.55	0.53	0.35	0.17	0.17	
		Panicle initiation stage, 68 days					
1. Water stress	Granulated	6.8	5.7	5.1	2.4	0.9	4.2
2. W. table -5-10cm	Granulated	16.9	17.6	14.7	2.3	2.4	10.8
3. Flooded	Granulated	16.8	13.6	16.3	5.7	2.7	11.0
4. Delayed flooding	Granulated	19.4	17.6	7.0	2.3	1.6	9.6
5. Flooded	Puddled	16.5	18.7	24.5	5.2	5.4	14.0
Mean		15.3	14.6	13.5	3.6	2.6	
		Grain yields at harvest, 111 days					
1. Water stress	Granulated	1.7	4.9	3.4	1.6	0.4	2.4
2. W. table -5-10cm	Granulated	16.1	19.1	20.9	6.1	5.0	13.4
3. Flooded	Granulated	18.0	22.0	25.2	15.3	11.1	18.3
4. Delayed flooding	Granulated	18.4	20.5	24.2	10.6	8.8	16.5
5. Flooded	Puddled	18.7	21.9	29.6	14.4	11.5	19.2
Mean		14.6	17.7	20.7	9.6	7.3	
		Total dry matter at harvest					
1. Water stress	Granulated	18.6	22.6	12.2	5.9	4.5	12.7
2. W. table -5-10cm	Granulated	37.8	41.1	42.1	15.0	13.1	29.8
3. Flooded	Granulated	41.1	45.4	46.3	28.5	23.3	36.9
4. Delayed flooding	Granulated	40.0	45.4	46.9	21.4	18.3	34.4
5. Flooded	Puddled	39.0	43.2	54.3	28.1	22.4	37.4
Mean		35.3	39.5	40.4	19.8	16.3	

HSD .05

	Means	Interactions
Tillering	0.07	ns
Panicle initiation	2.0	4.8
Grain yield	2.1	5.0
Total dry matter	4.1	9.8

Table 3. Effect of soil and water management on P uptake by rice at several stages of growth.

Water management	Physical condition	Soils: Maahas	Quingua	Faraon	Buenavista	Isarog	Mean soils
		Phosphorus uptake, mgP/pot					
		Tillering stage, 27 days					
1. Water stress	Granulated	1.7	1.8	0.5	0.2	0.2	0.9
2. W. table -5-10cm	Granulated	1.6	2.0	0.8	0.2	0.1	0.9
3. Flooded	Granulated	2.0	1.5	0.6	0.3	0.3	0.9
4. Delayed flooding	Granulated	2.0	1.8	0.9	0.3	0.2	1.0
5. Flooded	Puddled	3.1	2.1	1.3	0.2	0.3	1.4
Mean		2.1	1.8	0.8	0.2	0.2	
		Panicle initiation stage, 68 days					
1. Water stress	Granulated	13.6	12.0	7.6	1.2	0.4	7.0
2. W. table -5-10cm	Granulated	32.1	33.4	17.6	1.6	1.8	17.3
3. Flooded	Granulated	43.7	35.3	28.1	4.7	2.4	22.8
4. Delayed flooding	Granulated	36.2	42.2	11.2	1.8	1.9	22.7
5. Flooded	Puddled	46.2	48.6	44.1	4.7	3.8	29.5
Mean		38.4	34.1	21.7	2.8	2.0	
		Harvest, 111 days					
1. Water stress	Granulated	26.0	23.0	14.0	1.3	2.0	13.2
2. W. table -5-10cm	Granulated	71.7	80.5	37.9	6.3	10.1	41.7
3. Flooded	Granulated	77.0	104.6	64.5	19.8	27.7	58.7
4. Delayed flooding	Granulated	80.2	93.8	89.0	18.4	21.9	60.7
5. Flooded	Puddled	72.1	95.2	53.1	19.7	27.2	53.4
Mean		65.8	79.4	51.8	13.1	17.8	

HSD .05

	Means	Interactions
Tillering	0.3	ns
Panicle initiation	3.7	9.0
Harvest	6.6	16.0

Table 4. Redox potential of the soil solution extracted from granulated soils as affected by water table level.

Treatment	Water table	Soil: Maahas	Quingua	Faraon	Buenavista	Isarog	Mean
	cm	Eh, in m.v.					
Aerobic	None	245	165	12	179	173	148
Unflooded	-5 to -10	33	175	122	164	62	111
Flooded	+2 to + 4	-71	-132	-217	-201	-142	-153

Table 5. Effects of puddling and phosphorus on rice grain yields and yield components grown on a Typic Dystrandept with a water table at 15 cm below the soil surface.

Physical condition	P added	Grain yields	Panicles per drum	Grains per panicle	100 grain weight
	ppm	g/drum			grams
Puddled	0	71	90	56	2.22
Puddled	100	83	116	66	2.26
Granulated	0	130	110	73	2.30
Granulated	100	204	164	89	2.18
LSD .05		18	8	12	0.14
CV		6	3	8	3

redox status. The Buenavista and Isarog soils were visually deficient in P in both treatments, but the flooded treatments produced more than twice the P uptake at panicle initiation, which also resulted in twice the grain yields and P uptake at harvest. The % P in all tissues sampled was higher under flooded conditions.

These results show that the effects of keeping a partially reduced soil profile depended on the availability of the soil to supply P and that yield reductions can take place in soils of low P availability. In soils of high P availability keeping a water table below the soil surface will not decrease yields but will decrease water consumption by $^1/_3$. It should be noted that these soils were well supplied with other nutrients such as Fe, Mn and Si, whose solubility is influenced by flooding, as evidenced by tissue analysis (11).

Effects of Delaying Flooding—The effects of flooding at 15 vs 35 days after seeding can be shown by comparing Treatments 3 and 5. No differences were observed by delaying flooding in the Maahas and Quingua soils. In the Faraon soil, delaying flooding decreased both dry matter and P uptake at the panicle initiation stage by 50%. These differences gradually disappeared, and at harvest, delaying flooding had no effect on grain yield or total dry matter, although it resulted in a significant decrease in P uptake.

In the Buenavista and Isarog soils, delaying flooding drastically decreased dry matter production and P uptake at the panicle initiation stage and produced lower grain yields, although the difference was not significant in the case of Buenavista. Phosphorus uptake at harvest, however, was not affected by these treatments. Delayed flooding also accelerated the visual appearance of P deficiency symptoms by 10 days and retarded plant height and tiller production patterns by 10 to 20 days, flowering by 2 weeks, and harvest by 1 week.

These results indicate that the effects of delaying submergence are also related to the P availability of the soils. As in many other crops, P is critical at early stages of rice growth (3). In soils of high P availability delaying flooding is not detrimental to yields. In soils of moderate P availability delayed flooding resulted in a temporary reduction in growth and P uptake, while in soils of low P availability delaying flooding decreased yields.

Effects of Puddling—The influence of puddling in constantly flooded soils can be shown by comparing Treatments 3 and 4. Puddling significantly increased dry matter production and P uptake at 27 days after seeding and to a lesser extent at 68 days after seeding. However, no significant differences due to puddling were observed in grain yields, dry matter production, or P uptake at harvest. The % P in the plants at all stages of growth in the five soils was very similar between the two treatments. Increases in dry matter production at 27 and 68 days were not related to higher nutrient contents of other elements except for higher % N in plants growing in the Faraon soil at the panicle initiation stage. The effects of puddling were temporary and had no relationship to yields. The belief that puddling increases P availability (6, 7, 8) is not supported by this experiment.

The effects of puddling in soils with a water table kept at 15 cm below the surface in Experiment 2 are shown in Table 5. During this dry season, soil shrinkage in the puddled treatments restricted root development to the top 2 to 4 cms, while roots developed normally in the granulated soils. Growth in the puddled soils was severely limited while excellent growth took place in the granulated ones. Responses to applied P in the puddled soils were not significant — presumably due to root development restrictions — while significant P responses were observed in the granulated treatments. These results also confirm previous findings that shrinkage of unflooded puddled soils can severely restrict rice growth (12).

P Uptake as Related to P Soil Test—P uptake was not closely related with soil test results obtained with the extractant most commonly used in the Philippines. Although it is well known that P soil tests for rice are not so successful as those for other crops (3), the failure of the Bray 2 test to distinguish between Quingua, the soil on which rice produced the highest P uptake in all management treatments (Table 3), and the Isarog or Buenavista soils, which produced the lowest P uptake, underlines the necessity of further studies on this subject.

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