Fertilizer Research **41**: 11–17, 1995.

Response of upland rice to phosphorus in an Ultisol in the humid forest zone of West Africa

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Received 5 July 1994; accepted in revised form 11 February 1995

Key words: *Oryza sativa*, grain yield, agronomic and physiological P efficiencies, harvest index, rooting depth

Abstract

Phosphorus (P) deficiency is one of the major limiting factor for crop production in highly weathered soils in the humid tropics. Field experiments were conducted for two years (1992 and 1993) to determine P response and efficiencies of upland rice cultivars in an Ultisol, low in available P, in the forest zone of Cote d'Ivoire. The rice cultivars tested were selected from a large number of entries tested earlier for acidity tolerance.

Grain yields of the cultivars were significantly increased by P application. There was little further response in grain yield at higher rates than 60 kg P ha^{-1}. The rice cultivars differed in agronomic and physiological P efficiencies and the efficiencies were higher at lower rates of P. The rooting depths of the cultivars were increased by application of P at the lowest application rate (30 kg P ha^{-1}).The results suggest that P fertilization of soil acidity-tolerant upland rice cultivars can significantly improve the productivity of the Ultisols.

Introduction

Phosphorus (P) deficiency has been identified as one of the major limiting factors for crop production in highly weathered soils such as Oxisols and Ultisols in the tropics (Sanchez and Salinas, 1984; Warren, 1992). Availability of P in these soils is reduced by the reaction of soluble P with iron and aluminum oxides (Juo and Fox, 1977; Mokwunye *et al.*, 1986). Despite a great deal of research on soil P much still remains to be learned about the management of low P, acid soils in relation to the P requirement of upland rice in the humid tropics of West Africa.

The aim of this study was to measure the P responsiveness of selected upland rice cultivars and to determine their P requirements and efficiencies in an Ultisol low in available P.

Materials and methods

Field experiments were conducted in 1992 and 1993 at the IDESSA (Institut des savannes) station near Man (7.2°N, 7.4°W; altitude 500 m) to measure P response of five upland rice cultivars in an Ultisol in the humid forest zone of Cote d'Ivoire. The site receives on average an annual rainfall of about 1700 mm. The site was under a bush-fallow for the last three years before initiation of the study. The secondary vegetation was dominated by *Chromolaena odorata*.

Soil

The soil at the experimental site is an Ultisol low in extractable P. Some important characteristics of the soils at the two nearby experimental sites during 1992 and 1993 are given in Table 1. The soil samples were collected from two soil depths (0–20 and 20–40 cm) before initiating the experiments, air-dried and ground to pass a 2-mm screen before analysis. For the analyses reported in Table 1, pH was measured by a glass electrode using a soil to water or salt (1 *M* KCl) solution ratio of 1: 2.5. Organic C was determined as described by Walkley and Black (1934). Total P content in the soil was determined by digestion with perchloric acid and the extractable P was determined using NH_4F-HCl solution, generally referred to as Bray 1, to extract P

Table 1. Some characteristics of the soil (0–20 cm and 20–40 cm depths) at the P experimental sites near Man, Cote d'Ivoire

Characteristic	1992		1993	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
pH (water)	4.8	4.7	4.9	4.8
pH (KCl)	4.0	3.9	4.0	4.0
Organic C (g kg^{-1})	0.150	0.120	0.135	0.100
Total P (mg kg^{-1})	150	132	155	125
Bray 1P (mg kg^{-1})	2.9	2.0	2.7	1.8

using a soil to extractant ratio of 1:7 (Olsen and Sommers, 1982).

Field experiments

Field experiments were conducted in the 1992 and 1993 rainy seasons near Man in the western part of Cote d'Ivoire to measure P response of upland cultivars. The land was cleared by slashing the vegetation and the slashed vegetation was taken off the plots. The land was prepared by harrowing and disc plowing to obtain a good seed bed.

In 1992, four rates of P (0, 30, 60 and 90 kg P ha^{-1} as triple superphosphate) were used to test the P response of five promising upland rice cultivars (WAB 56-125, WAB 56-104, WAB 56-50, IDSA 6 and ITA 257). The fertilizer was applied plot-wise by broadcasting and incorporating in the top 5–6 cm soil layer. Seeds were hand drilled along the rows at a uniform depth and covered with soil. The rice cultivars tested were selected from a large number of entries tested earlier for acidity tolerance. A randomized complete block design was used, with four replications. The cultivars were sown at a spacing of 25 × 25 cm. Each plot (5 × 3 m) received N (total 100 kg N ha^{-1}) in three splits at planting, tillering and flowering. Plots were hand weeded at 3 and 6 weeks after seeding. To determine rooting response to P, the root distributions of the five cultivars were studied at flowering stage of the crop in two out of the four replications, using a 60 × 30 cm grid with 72 squares, each measuring 5 × 5 cm. Trenches were dug to expose the roots down the profile and they were then measured using the grid. In 1993 the experiment was repeated at a nearby site with a higher P range (0, 45, 90 and 135 kg P ha^{-1} as triple superphosphate) on four cultivars. The variety ITA 257, sensitive to soil acidity was not included in 1993. Other details of the experiment were the same as in 1992.

The crops were harvested at maturity and grain and straw weights were recorded at 14% moisture. The grain and straw samples were analysed for P by digesting the samples with a 2:1 mixture of nitric and perchloric acids. The P in the digests was analysed following the vanadomolybdate yellow colour method. The data were analysed statistically using analysis of variance.

Results and discussion

Grain yield response

The rice yields were in general lower in the 1993 season than in 1992. This might have been due to the fact that less rainfall was received during the growing season (June through October) in 1993 (953 mm) than in 1992 (1100 mm). The average total annual rainfall at the site is about 1700 mm.

The phenology of the rice cultivars was affected by fertilizer P application. For example, in 1992 season, the number of days to 50% flowering were reduced by 9 to 11 days and the days to physiological maturity were reduced by 4 to 9 days for the 5 cultivars by the first rate of P (30 kg P ha^{-1}) application. An increase in the rate of P application beyond 30 kg P ha^{-1} did not further affect the phenology of the cultivars (Table 2). These results show that P application in low-P status soils may be important for hastening flowering and maturity of the rice crop. The 1992 data on grain yield responses of the 4 cultivars to applied P along with the response functions are shown in Figure 1. The P responses of WAB 56-125, WAB 56-50 and ITA 257 cultivars were best described by quadrat-

Table 2. Effects of fertilizer P on yield parameters of five upland rice varieties, Man, 1992. The values in parentheses are the standard deviations of means

P rate (kg ha^{-1})	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6	ITA 257
			Days to 50% flowering		
0	91(6.6)	86(3.8)	90(8.1)	104(3.4)	90(6.2)
30	80(1.1)	76(1.1)	80(1.2)	95(0.0)	79(1.6)
60	79(0.0)	76(3.8)	80(3.0)	95(1.0)	79(3.0)
90	78(2.0)	73(2.3)	79(1.6)	92(1.0)	77(2.5)
			Days to physiological maturity		
0	120(4.9)	117(2.9)	120(5.1)	128(1.5)	114(4.5)
30	112(1.4)	109(0.0)	111(0.0)	124(1.9)	108(1.9)
60	111(0.0)	109(1.0)	112(3.5)	123(1.0)	105(1.6)
90	108(2.5)	106(1.2)	112(2.5)	120(1.0)	105(0.0)
			Number of panicles m^{-2}		
0	119(40.7)	140(14.4)	123(34.8)	110(34.0)	91(12.9)
30	138(10.5)	148(21.8)	178(19.7)	140(36.6)	119(23.6)
60	155(24.7)	170(24.0)	165(16.5)	130(25.0)	94(14.6)
90	150(13.7)	160(19.2)	165(16.8)	144(26.1)	107(32.6)
			1000-grain wt, g		
0	31(2.0)	33(1.2)	30(2.3)	28(1.0)	31(1.6)
30	33(0.5)	34(1.7)	32(0.7)	28(0.8)	33(1.8)
60	33(0.5)	33(1.3)	33(0.5)	28(1.7)	32(1.6)
90	32(0.8)	33(1.7)	32(0.6)	28(0.6)	32(2.0)

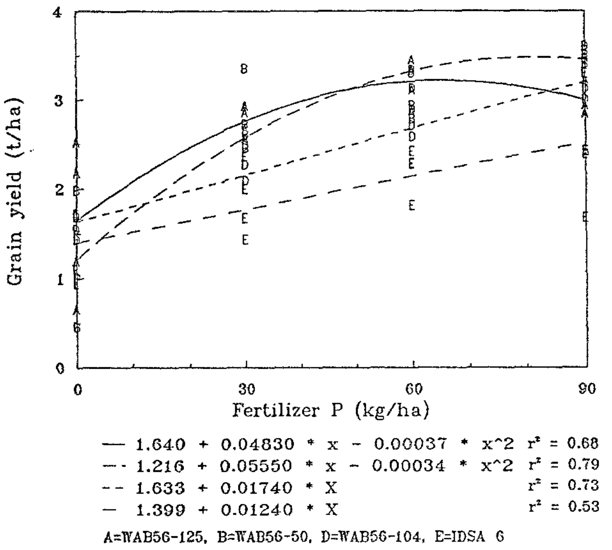

Fig. 1. Relationships between grain yield and different fertilizer P rates of four rice cultivars in 1992.

ic functions while those of WAB 56-104 and IDSA 6 were described by linear functions. Without applied P, WAB 56-125 gave the highest grain yield followed by WAB 56-104, IDSA 6 and WAB 56-50. P response in the case of ITA 257 was not significant because of a severe disease incidence.

The respective P response equations for the four cultivars in 1992 were:

WAB 56-125: $Y = 1.640 + 0.04830\,X - 0.00037\,X^2$, $r^2 = 0.68$

WAB 56-50: $Y = 1.216 + 0.05550\,X - 0.00034\,X^2$, $r^2 = 0.79$

WAB 56-104: $Y = 1.633 + 0.01740\,X$, $r^2 = 0.73$

IDSA 6: $Y = 1.399 + 0.01240\,X$, $r^2 = 0.53$

where Y is the grain yield in t ha^{-1} and X is the rate of applied P in kg ha^{-1}. The P response curves for the 4 cultivars in the 1993 experiment are shown in Figure 2. Without applied P, WAB 56-50 gave the highest

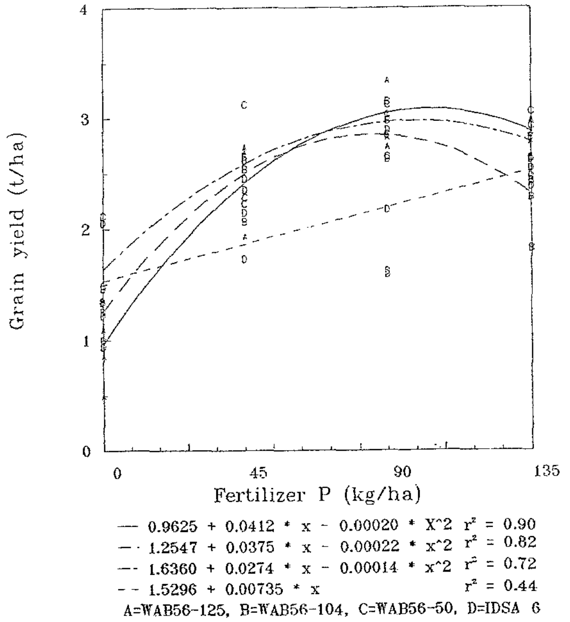

Fig. 2. Relationships between grain yield and different fertilizer P rates of four rice cultivars in 1993.

yield closely followed by IDSA 6 and WAB 56-104. As in 1992, the P response of the cultivar IDSA 6 was better described by a linear function while for the other cultivars it was described by a quadratic function.

The P response equations for the four cultivars in 1993 were as follows:

WAB 56-125: $Y = 0.9625 + 0.0412\,X - 0.00020\,X^2$, $r^2 = 0.90$

WAB 56-104: $Y = 1.2547 + 0.0375\,X - 0.00022\,X^2$, $r^2 = 0.82$

WAB 56-50: $Y = 1.6360 + 0.0274\,X - 0.00014\,X^2$, $r^2 = 0.72$

IDSA 6: $Y = 1.5296 + 0.00735\,X$, $r^2 = 0.44$

It is interesting to note that the cultivar IDSA 6, which is widely grown in the region in the uplands, gave a linear response to applied P over a range of P rates.

Root response to applied P

The distribution of roots of the five varieties at four rates of P application (0, 30, 60 and 90 kg P as triple superphosphate) in the 1992 season is shown in Figure 3. For most varieties rooting depth and density increased with the application of P, with the largest response obtained at the lowest rate of P application (30 kg P ha^{-1}). Without applied P, most roots were confined to the top 30 cm depth. When no P was applied, WAB 56-104 and WAB 56-50 had deeper rooting followed by IDSA 6. With the application of P, rooting depth increased to about 60 cm in all the cultivars with IDSA 6 showing the deepest root development.

These results show that application of P can increase rooting depth and density in an Ultisol low in available P. This should enable a cultivar to obtain extra nutrients and water from a larger volume of the soil. The exploration of higher soil water in the profile is not only important for overcoming drought but also should lead to better utilization of soil and applied nutrients.

Agronomic P efficiency of the cultivars

Agronomic P efficiency of the cultivars was calculated as the increase in grain yield by application of P and is expressed as kg grain kg^{-1} P applied. In 1992 the agronomic efficiency of the cultivars was highest at 30 kg P ha^{-1} rate and varied from 18 to 54 kg grain kg^{-1} P applied with WAB 56-50 showing the highest efficiency and IDSA 6 the lowest (Table 3). The agronomic P efficiency of the cultivars decreased with the higher rates of applied P. The average agronomic P efficiency of the four cultivars (averaged over the three rates of P) varied from 15 to 37 kg grain kg^{-1} P. The cultivar WAB 56-50 was the most efficient, followed by WAB 56-104, WAB 56-125 and IDSA 6 (Table 3).

Agronomic efficiency for the four cultivars was lower in 1993 than in 1992 (Table 4). This was due to less total rainfall received during the growing season in 1993 compared to that received in 1992. The P efficiency for the 1993 season was computed only for the 45 and 90 kg P ha^{-1} rates because no significant P response was obtained beyond the 90 kg P ha^{-1}. The agronomic P efficiency of the cultivars varied from 14 to 29 kg grain kg^{-1} P at 45 kg P ha^{-1} rate and varied from 6 to 18 when P was applied at a rate of 90 kg P ha^{-1} (Table 4).

A grain yield efficiency index (GYEI) proposed by Fageria *et al.* (1988) and that assesses the yield stability of the cultivars, was also used to compute the efficiency of the cultivars in 1992 and 1993 using the following equation:

$$\begin{array}{l}\text{Grain yield}\\ \text{efficiency index}\\ \text{(GYEI)}\end{array} = \frac{\text{Yield at low P level}}{\text{Mean yield at low P}} \times \frac{\text{Yield at high P level}}{\text{Mean yield at high P}}$$

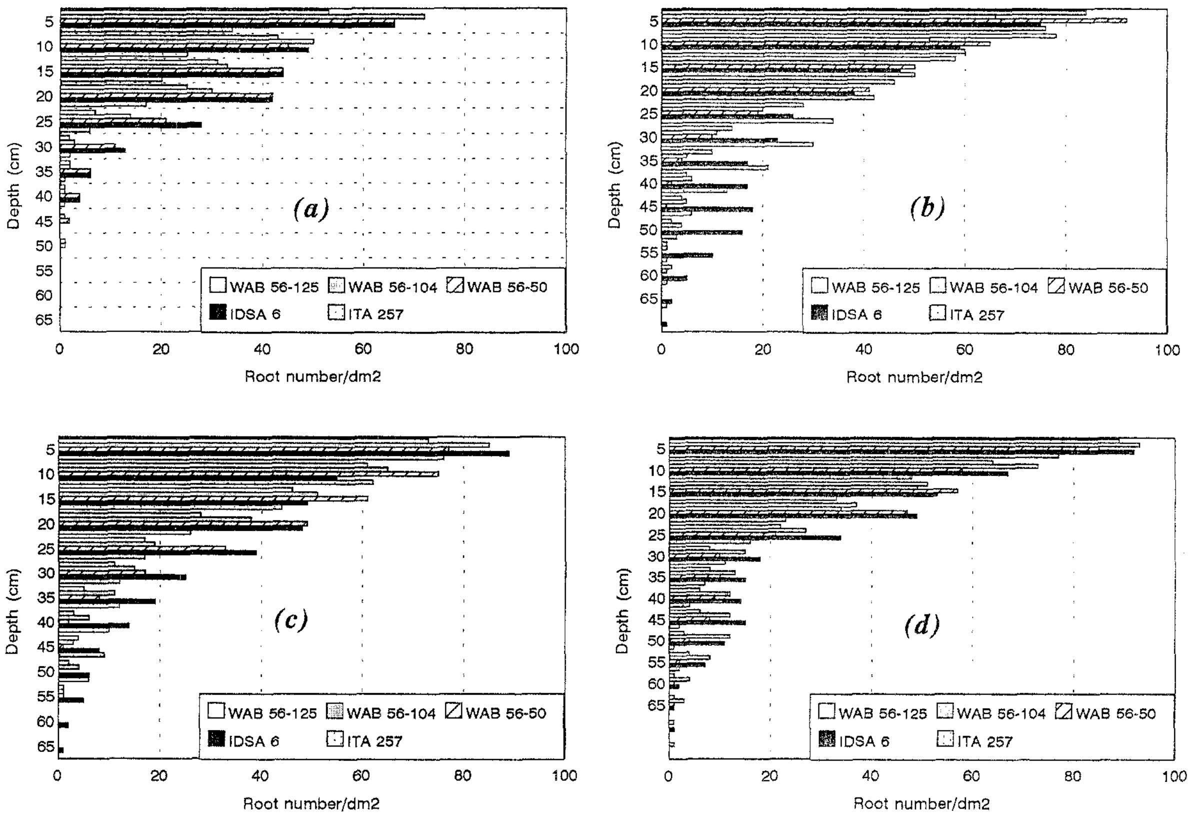

Fig. 3. Root response of five rice cultivars to applied P in an Ultisol in the humid forest zone, Cote d'Ivoire, 1992 : **(a)** 0 kg P ha^{-1}; **(b)** 30 kg P ha^{-1}; **(c)** 60 kg P ha^{-1}; **(d)** 90 kg P ha^{-1}.

Table 3. Agronomic P efficiency of four upland rice cultivars as affected by P fertilization, Man, 1992

P rate	P response (kg grain kg^{-1} P applied)			
(kg ha^{-1})	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6
30	37	32	54	18
60	26	23	32	15
90	15	18	26	12
Av, P rates	26	24	37	15

Table 4. Agronomic P efficiency of four upland rice cultivars as affected by P fertilization, Man, 1993

P rate	P response (kg grain kg^{-1} P applied)			
(kg ha^{-1})	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6
45	29	20	20	14
90	18	14	14	6
Av, P rates	23	17	17	10

Table 5. Grain yield efficiency index (GYEI) of four upland rice cultivars, Man

Cultivar	1992	1993
WAB 56-125	1.11	1.17
WAB 56-104	0.99	1.08
WAB 56-50	1.33	1.13
IDSA 6	0.62	0.66

For the 1992 experiment, the low and high rates of P used for computation were 30 and 90 kg P ha^{-1} while for 1993 they were 45 and 90 kg P ha^{-1}. For 1993 experiment there was no significant response to applied P beyond 90 kg P ha^{-1}. Mean yield refers to the mean yield of the four cultivars tested.

The data on GYEI for the four cultivars is shown in Table 5 and it is clear that GYEI was highest for WAB 56-50 or WAB 56-125 and IDSA 6 had the lowest value. These results support the trends in the results obtained using agronomic P efficiency index in comparing the efficiency of the rice cultivars (Tables 3 and 4).

Table 6. Physiological P efficiency of four upland rice cultivars as affected by P fertilization in Man, 1992

P rate	P response (kg grain kg^{-1} P uptake)			
(kg ha^{-1})	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6
30	542	542	588	537
60	508	519	571	504
90	461	507	517	411
Av, P rates	504	523	559	484

Table 7. Harvest index of the four cultivars as affected by P fertilization, Man, 1992

P rate	Harvest index			
(kg ha^{-1})	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6
0	0.526	0.495	0.418	0.455
30	0.552	0.537	0.519	0.470
60	0.596	0.605	0.541	0.459
90	0.517	0.575	0.546	0.485

Physiological P efficiency of the cultivars

Physiological P efficiency of the four cultivars in 1992 was computed from the P uptake data and is presented as kg grain kg^{-1} P uptake (Table 6). The physiological P efficiency of the cultivars was highest at 30 kg P ha^{-1} and decreased with the increasing rate of the applied P and was lowest at 90 kg P ha^{-1} rate. Among the cultivars, WAB 56-50 showed the highest efficiency, followed by WAB 56-104, WAB 56-125 and IDSA 6 in the decreasing order.

The poor efficiency of IDSA 6 is mainly due to its lower harvest index (ratio of grain yield to grain plus straw yield) than the other three cultivars (Table 7). IDSA 6 has the lowest harvest index and it was only slightly improved by P fertilization. On the other hand each of the WAB cultivars had higher harvest indices and P application caused further better improvement.

IDSA 6 was efficient in taking up P from the soil but transferred a greater proportion of it to straw compared to the WAB cultivars. For example, when no P was applied, IDSA 6 took up 1.92 kg of P from the soil which is lower than the P taken up by WAB 56-125 (2.41 kg P) but is higher than P uptake by WAB 56-104 (1.86 kg P) and WAB 56-50 (1.62 kg P).

Additionally, the data on yield-contributing parameters of the cultivars in the 1992 season showed that IDSA 6 produced less number of panicles m^{-2} and also the cultivar had a lower 1000-grain wt compared to the WAB cultivars (Table 2). The cultivar IDSA 6 is ideally suited for low-input, upland rice cultivation because of its general robustness and drought resistance. Infact, IDSA is one of the parents for the WAB cultivars and thus the WAB lines have drought resistance as does IDSA 6. Additionally, the WAB cultivars have a shorter growing cycle and higher harvest indexes than IDSA 6 and therefore may be better suited for rice cultivation under upland conditions. The WAB cultivars are now under test in the region for their performance under diverse upland rice growing conditions.

Earlier studies on the P response of upland rice cultivars in an Oxisol in Brazil showed that genetic differences exist in P use efficiency and that the P efficiency was higher under low P levels (Fageria *et al.*, 1988) which are in accord with the results obtained in our study.

In summary, the results of this two year study indicate that marginal response (kg grain kg^{-1} of applied P) to applied P is maximized at around 60 kg P ha^{-1} and there is little response at higher rates. The cultivars differ in agronomic and physiological P efficiencies and efficiencies are higher at lower rates of P. The rooting depth of the cultivars can be increased by application of P in the Ultisols low in available P. Application of P is also important for hastening flowering and maturity of rice in low-P status soils.

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