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Effect of phosphorus on drought mitigation and productivity of rainfed upland rice (*Oryza sativa*)

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ABSTRACT

The effect of phosphorus application at varying rates, viz. 0, 12, 24, 48 and 96 kg/ha, was studied on drought mitigation and productivity of two upland rice *(Oryza sativa* L.) varieties ('Vandana' and 'Annada') during 1999, 2000 and 2001 under rainfed upland condition at Hazaribag in Jharkhand. Phosphorus was applied basal through single superphosphate along with common doses of N, K, Zn and Mg. The effects of P rates, and interaction effects between P rates and varieties were significant in the drought year only (2000). Reduction in grain yield due to drought in no-P plots was 27.4% in 'Vandana' and 58.4% in 'Annada' in comparison with normal rainfall year (1999). The grain yield of 'Annada' and 'Vandana' decreased by 11.7 and 25.4 at 24 kg P/ha, and by 2.5 and 5.2 at 48 kg P/ha respectively. Maximum P-use efficiency was achieved at 24 kg P/ha in both the varieties. Concentration of P in grain and straw was also reduced due to drought in 2000 at low P application compared with that in 1999. Differences in agronomic P-use efficiency were apparent due to varieties. Agronomic P-use efficiency was 38.1 kg grain/kg P in 'Annada' compared with 15.5 kg grain/kg applied P in 'Vandana'. However, differences due to varieties in relative effect of drought stress (RDS) and available soil P were marginal. It was concluded that the application of P @ 24 kg/ha helped in reducing the effect of drought as well as in increasing the rice productivity and P-use efficiency of rainfed upland rice.

Key words : Drought mitigation, P rates, Rainfed upland rice, Grain yield, P uptake, Relative effect of drought stress

Upland rice *(Oryza sativa* L.) in India is planted in 6 million ha in low-fertility acid soils, and P deficiency is one of the most important yield-limiting factors. Average yield of upland rice in India is 1 t/ha or below. The availability of P in upland acid soils is reduced due to high fixation of P in the soil (Kirk *et al.,* 1998; Hedley *et al.*, 1994) due to interaction of soluble P with iron and aluminum oxides (Warren, 1992). Sahrawat *et al.* (1995) identified phosphorus deficiency as one of the major limiting factors in highly weathered upland soils in the tropics. In addition to P deficiency, drought and cultivars also play major role in determining the upland rice productivity (Singh *et al.,* 2000). High variations among rice cultivars for P uptake were observed on P-deficient soils by Wissuwa and Ae (2001). Despite intensive research on soil P and its effect on upland-rice productivity, much still remains to be studied about management of low-P acid soils in eastern India. The objective of this study was to explore the possibilities of mitigating adverse effects of drought on productivity of rainfed upland rice by P application.

MATERIALS AND METHODS

An experiment was conducted at Central Rainfed Upland Rice Research Station, Hazaribag to compare the effect of P application on upland rice in no-drought year (1999), drought year (2000) and mild-drought year (2001). The soil was clay loam, acidic with pH 5.8; organic C, 0.78%; total N, 0.09%, Mehlich 1 P, 16.8 kg/ha and exchangeable Ca, Mg, K and Na, 13.6, 4.0, 0.7 and 0.7 meq/100 g respectively (Jackson, 1973).

Phosphorus was applied @ 0,12, 24, 48 and 96 kg P/ha on soil-test basis (the available soil P was estimated before and after every harvest and only deficit quantity of P as per treatment was applied to maintain the P rates) to make the required amount available to the crop every year as per treatment. Two popular rice varieties, viz. 'Vandana' (95 days) and 'Annada' (105 days) were included in the experiment. A factorial randomized complete block design was used with four replications. The crop was sown in rows at a spacing of 20 cm in the last week of June every year. Plot size was 10 m × 6 m. Finely-ground single superphosphate was thoroughly incorporated in plough layer before sowing. All the plots received uniformly 75 kg N/ha in five splits from seeding to flowering at 15 days interval; and K, Zn and Mg as basal @ 100 kg, 15 kg/ha and 25 kg/ha in the form of muriate of

potash, zinc sulphate and magnesium sulphate respectively. The plots were hand-weeded at 21 and 40 days after sowing and weeds were incorporated in the soil.

Rainfall during the crop-growth period was 890.9, 780.8 and 811.9 mm, received in 58, 43 and 51 rainy days during 1999, 2000 and 2001 respectively. In 2000, the shorter-duration rice variety 'Vandana' experienced drought for 10 days at booting-flowering, and 8 days at grain filling, whereas the relatively longer-duration variety 'Annada' experienced drought for 10 days at booting, 8 days at flowering and 9 days at grain-filling stages. In 2001 also, 'Annada' suffered moisture stress for 8 days at grain-filling stage, by which time 'Vandana' was already harvested.

Grain and straw yields were recorded on dry-weight basis, by drying the samples at 70° C for 48 hr. Grain and straw samples were analysed for P, following the Vanado-molybdate yellow-colour method. The data were analysed using IRRISTAT software. To evaluate the effect of different P rates in mitigating drought, relative effect of drought stress (RDS) was calculated using the following formula (Rodriguez *et al.*, 1996).

RDS = (Yw—Yd)/Yw × 100

where Yw = Yield of crop in normal-rainfall year; Yd=Yield of crop in drought year.

RESULTS AND DISCUSSION

Grain and straw yields

Grain yield of rice variety 'Annada' was consistently higher than of 'Vandana' in all the years (Table 1). However, the effect of P rates and interaction between P rates and varieties was significant in the drought year 2000. In this year, maximum grain yield was recorded at 96 and 48 kg P/ha in 'Annada' and 'Vandana' respectively, but differences were statistically significant only up to 24 kg P/ha. Reduction in grain yield due to drought in no-P plots was 27.4% in 'Vandana' and 58.4% in 'Annada' in comparison with that in normal-rainfall year 1999. This could be attributed to genetical variations existing among upland rice cultivars for P uptake on P-deficient soils. These findings corraborate the findings of Wissuwa and Ae (2001). As duration of test cultivars was not identical and crop-growth stage of the cultivars coinciding with moisture stress also differed, this could also be a reason for different response of rice varieties during the drought year. Comparison of higher P rates during normal and drought years showed that the reduction in yield of 'Annada' and 'Vandana' was 11.7 and 25.4 percent at 24 kg P/ha, and only 2.5 and 5.24 percent at 48 kg P/ha respectively. Lesser reduction in rice-grain yield at high P application was due to greater uptake of P by the rice plant. The P concentration in grain was more at its higher application and its concentration in the rice plant decreased significantly at lower rates. The application of low amount of P was not sufficient to meet its demand by the rice plant. He *et al.* (2004) also reported decrease in available soil-P content with the decrease in soil-moisture content and P application. Under adverse environmental conditions, high P supply increased the potential hydraulic conductance of the root per unit leaf area, leaf-expansion rate, size of the cell, and the size and number of vacuoles in each cell to store more solute and water in crops like wheat, cotton and white clover (Singh *et al.*, 2003). Straw yield was influenced due to varieties in 1999 and due to P rates in 2000 only. 'Vandana' gave more straw yield than 'Annada.' Application of 96 kg P/ha led to the higher straw yield of both the varieties but it was on a par with that of 24 kg P/ha. The data on grain-yield responses of both the rice varieties to P application in 2000 along with

Table 1. Effect of P application on grain and straw yields of rainfed upland rice

Treatment	Grain yield (t/ha)			Straw yield (t/ha)		
	1999	2000	2001	1999	2000	2001
Variety						
'Annada'	3.04	2.38	2.33	2.46	3.41	2.60
'Vandana'	2.28	1.84	2.01	2.94	3.13	2.66
CD (P=0.05)	0.32	0.24	0.29	0.29	NS	NS
P (kg/ha)						
0	2.30	1.41	1.86	2.48	2.44	2.48
12	2.64	1.48	2.25	2.65	2.50	2.89
24	2.82	2.31	2.29	2.64	3.49	2.48
48	2.82	2.72	2.34	2.80	3.89	2.80
96	2.72	2.61	2.11	2.92	4.04	2.51
CD (P=0.05)	NS	0.38	NS	NS	0.46	NS

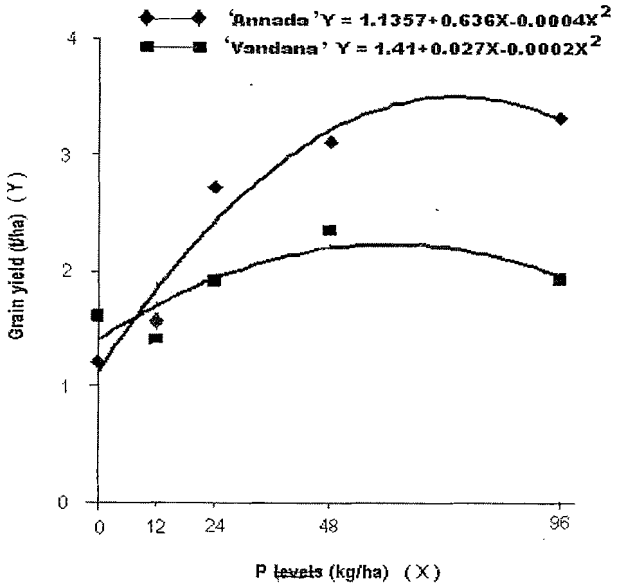

Fig. 1. Relationship between grain yield and P rates of two rainfed upland rice varieties during 2000

Table 2. Phosphorus uptake (kg/ha) by grain and straw of upland rice varieties under different P rates

Treatment	Grain			Straw			Total		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
Variety									
'Annada'	7.55	5.65	6.10	1.69	1.75	1.93	9.24	7.40	8.03
'Vandana'	7.70	4.18	5.85	2.04	1.57	1.79	9.74	5.75	7.64
CD (P=0.05)	NS	0.63	NS	0.29	NS	0.34			
P (kg/ha)									
0	6.60	2.36	4.25	1.67	0.96	1.53	8.27	3.32	5.78
12	7.02	2.55	5.57	1.81	1.08	1.94	8.83	3.63	7.51
24	7.60	4.32	6.32	1.79	1.42	1.68	9.39	5.74	8.00
48	8.73	7.02	6.98	2.02	2.11	1.96	10.75	9.13	8.94
96	8.18	8.34	6.76	2.02	2.74	2.21	10.2	11.08	8.97
CD (P=0.05)	NS	0.99	1.46	NS	0.60	NS			

the response function are shown in Fig. 1. Varieties differed in their response to P application, as evident by greater slope of the response curve of polynomial nature in 'Annada' than in 'Vandana'.

P concentration and uptake

Variations among varieties in grain-P content were non-significant in the drought year. Rainfall did not influence the P content in straw of both the varieties in all the years. Application of P failed to influence its content in straw and grain in the normal-rainfall year (1999) but showed significant effect in 2000 and 2001. In 2000 the P concentration in grain and straw of 'Vandana' decreased by 51.9 and 41.2% respectively compared with that in 1999 (where no P was applied). The decrease in P concentration in grain and straw due to drought was 17.3 and 4.2% respectively at 96 kg P/ha. In 'Annada' the decrease in its concentration in grain was lower (29.7%) than in 'Vandana' in the plots where no was applied and there was no decrease at the maximum P level. At intermediate level of P (12 kg P/ha), more biomass was produced but the concentration of P in grain and straw was not as high as was observed at 96 kg P/ha, and therefore drought tolerance was not developed. This might be due to low availability of soil P to the rice plant at inermediate level. These observations are in agreement with those of Rodrigue *et al.* (1996). Application of 24 kg P/ha increased the grain-P upake significantly in 'Annada', whereas at 48 kg P/ha it was significantly more at 48 kg P/ha in 'Vandana' than in the control (Table 2).

Maximum P-use efficiency was recorded with 24 kg P/ha in both the varieties in 2000, when the effect of P was significant on grain yield (Table 3). Further, the increase in P rates decreased the P-use efficiency.

Relative effect of drought stress

Relative effect of drought stress (RDS), calculated on the basis of 1999 as normal year and 2000 as drought year, decreased with P application in 'Annada' (Table 3). P at 48 kg/ha minimized the drought effect on yield, and at 96 kg/ha negated the drought effect. The RDS values were least at 48 kg P/ha in 'Vandana' and also when averaged over both the varieties. The effect of drought was more at lower level of P and *vice-versa.* Nye and Tinker (1997) reported that when little water is available, P ions become less mobile because air space replaces water in the pores between the soil particles. Effect of P rates on residual P showed that build up of available P was maximum at 96 kg P/ha, followed by that at 48 P/ha (Table 3).

Table 3. Effect of varieties and P levels on agronomic P-use efficiency (APUE), relative effect of drought stress (RDS) and residual available soil P

Treatment	P-use efficiency (kg grain/kg applied P)	RDS (%)	Available soil P (kg/ha)		
			1999	2000	2001
Variety					
'Annada'	38.1	24.1	8.9	18.4	30.4
'Vandana'	15.5	23.2	9.1	21.6	33.0
P (kg/ha)					
0		47.4	7.0	6.1	9.0
12	22.5	43.1	7.2	5.6	10.0
24	41.7	18.5	7.4	8.9	14.0
48	29.4	3.9	9.6	25.9	43.7
96	13.6	5.4	14.0	53.7	82.0

It is inferred that application of P @ 24 kg/ha helped in reducing the effect of drought as well as in increasing the productivity and P-use efficiency of rainfed upland rice. Variety 'Annada' gave higher yield and showed greater drought tolerance than 'Vandana' at different P levlels.

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