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Rice cultivar evaluation for phosphorus use efficiency

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Abstract

Phosphorus deficiency is one of the most growth-limiting factors in acid soils in various parts of the world. The objective of this study was to screen 25 rice cultivars (*Oryza sativa* L.) at low, medium, and high levels of soil P. Number of tillers, root length, plant height, root dry weight and shoot dry weight were related to tissue P concentrations, P uptake and P-use efficiency. Shoot weight was found to be the plant parameter most sensitive to P deficiency. Significant cultivar differences in P use efficiency were found. Phosphorus use efficiency was higher in roots than shoots and decreased with increasing levels of soil P. Positive correlations were found among growth parameters such as plant height, tillers, root and shoot weight, and P content of roots and shoots. These results indicate selection of rice cultivars for satisfactory performance under low P availability can be carried out using shoot and root dry weight as criteria.

Introduction

Phosphorus deficiency has been identified as one of the major limiting factors for crop production in highly weathered soils such as the Oxisols and Ultisols in many parts of the world (Haynes, 1984; Sanchez and Salinas, 1981). The high capacity of these soils to fix P in forms largely unavailable to plants presents serious agronomic and economic constraints. Several soil properties, especially clay, Fe, and Al contents are closely related to the P sorption capacity of these soils. Due to low natural phosphorus and high fixation capacity, a heavy dose of P is needed to achieve high production on these soils (Fageria et al., 1982a; Yost et al., 1979).

Phosphorus deficiency in high P sorbing soils can be corrected by an initial application of a large quantity of P, repeated band application of a large quantity of P, or a combination of an initial broadcast application and repeated band applications (Yost et al., 1979). However, farmers are facing difficulties with increasing costs of fertilizers, especially in developing countries. An integrated fertilization-plant breeding approach seems likely to give more economically viable and practical results in the future. The possibility of exploiting genotypic differences in absorption and utilization of P to improve efficiency of P fertilizer use or to obtain higher productivity on P-deficient soils has received considerable attention in recent years (Baligar and Barber, 1979; Clark and Brown, 1975; Fageria and Barbosa Filho, 1982; Nielsen and Barber, 1978). The objective of this study was to evaluate rice cultivars/lines for phosphorus use efficiency. Phosphorus uptake efficiency defined as mg dry weight produced per mg of P absorbed by roots and shoots. Efficient genotypes with other desirable characteristics can be used directly in advance field trials or in breeding programs.

Materials and methods

A greenhouse experiment was conducted to evaluate the response of 25 rice cultivars/lines to low, medium and high levels of soil phosphorus. The soil used in the experiment was a dark red latosol (Typic Eutrustox) having an initial pH of 4.8, soil test P = 1, K = 41, Ca = 60, Mg = 50 and Al = 90 mg kg^{-1} soil. Phosphorus and K were extracted by way of the Mehlich 1 extracting solution (0.05 mol l^{-1} HCl + 0.0125 mol l^{-1} H_2SO_4). Phosphorus was determined by colorimetry and K by flame photometry. Aluminium, Ca, and Mg were extracted with 1 *M* KCl. Calcium and Mg were determined by titration with EDTA and Al by titration with NaOH.

Low, medium and high levels of soil P were established by adding triple superphosphate at rates that provided 1.1, 10.2, and 87 mg kg^{-1} of soil test P. Phosphorus levels were determined by soil analysis made at the time of planting. The experiment was conducted with 6 kg of soil contained in plastic pots. The basal application of fertilizers in each pot was 400 mg of N as $(NH_4)_2SO_4$, 960 mg of K as KCl, 1000 mg FTE-BR-12, a fritted glass material that provides micronutrients, and 15 g dolomitic lime. Each pot received a top dressing of 400 mg N on the 50th day after sowing. These basal fertilizer rates were based on the recommendations of Fageria et al. (1982b).

A factorial design was used with 25 cultivars × 3 P in a randomized complete block design. The treatments were replicated 3 times. All pots were watered to maintain soil moisture at approximately field capacity throughout the growing period. Plants were harvested 73 days after planting. After harvesting the tops, the roots were removed from each pot using a water jet. Roots were washed several times with distilled water. Plant material (roots and tops) was dried to constant weight in a forced-draft oven at about 75 °C and then milled. Ground plant material was digested with a 2:1 mixture of nitric and perchloric acids and analyzed for P colorimetrically.

Results and discussion

Analysis of variance (Table 1) revealed a highly significant (*P* = 0.01) difference between cultivars for plant height, tillers, root dry weights, P concentrations in shoots, P content of shoots and P efficiency ratio of shoots. Similarly, the effects of

Table 1. F values for analysis of variance of growth parameters, P concentration, P-uptake, and P-efficiency ratio of 25 rice cultivars

Source of variance	Plant ht.	Root length	Tillers	Dry root wt.	Dry shoot wt.	P conc. in shoot	P uptake in shoot	P conc. in root	P uptake in root	ER-P shoot	ER-P root
Cultivars	17.62**	1.59*	8.24**	2.29**	1.54 NS	3.20**	1.07 NS	0.84 NS	2.11**	1.92**	1.36 NS
P	380.62**	3.66*	298.53**	129.06**	445.45**	736.23**	644.22**	377.29**	213.61**	306.84**	355.96**
CV × P	2.65**	1.08 NS	1.30 NS	0.77 NS	0.84 NS	0.84 NS	0.88 NS	0.95 NS	0.95 NS	1.15 NS	1.38 NS

NS = Not significant; *, ** = Significant at 0.05 and 0.01 probability levels, respectively.
P-uptake = P concentration × dry wt.
P-efficiency ratio (ER-P) = mg dry wt./mg P in root or shoot.

Table 2. Influence of P levels on growth parameters, plant tissue P concentration and P uptake of 25 rice cultivars

Growth parameter or plant P status	Soil P levels		
	Low, (1.1 mg·kg^{-1})	Medium, (10.2 mg·kg^{-1})	High, (87 mg·kg^{-1})
Plant height (cm)	74.6c	101.4b	109.1a
Root length (cm)	41.4b	43.3a	43.4a
Tillers per 3 plants	4.5c	7.8b	10.5a
Dry root weight (g/3 plants)	0.9c	1.7b	2.8a
Dry shoot weight (g/3 plants)	2.0c	6.7b	12.4a
P conc. in shoot (mg·g^{-1})	1.2c	2.2b	2.7a
P uptake in shoot (mg/3 plants)	2.4c	14.7b	33.6a
P conc. in root (mg·g^{-1})	0.9c	1.8b	2.0a
P uptake in root (mg/3 plants)	0.8c	3.0b	5.7a

Values for each growth parameter and P uptake under different levels of P followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.
Data are averaged over cultivars.
†ER-P = mg dry wt/mg P in root or shoot.

soil P treatments were highly significant for all growth and P-uptake parameters. Except for plant height, interactions among cultivars and soil P levels were not significant.

Growth parameter and P uptake responses to soil P levels are presented in Table 2. All growth and P uptake parameters increased significantly with increasing levels of soil P. This means that the soil used in the experiment was appropriate for screening purposes. One of the prerequisites of varietal screening for mineral stress is that the growth medium should be deficient and/or toxic in the nutrient under study.

To identify which of the growth parameters is most sensitive to P deficiency, increases in number of tillers, plant height, root length, dry weight of root and shoot at medium and high P levels as compared to low P level were calculated (Table 3). Shoot dry weight exhibited the maximum increase in growth with P addition and was followed by dry weight of roots and tillers. Root length did not increase at the higher soil P levels. This means that shoot weight was the most sensitive response parameter to P deficiency. Root weight was the second most sensitive. These two growth parameters can, therefore, be used for rice genotype screening experiments. Shoot weight is much more easily determined as compared to root weight and is recommended for P-screening studies of cereals under greenhouse conditions.

Table 3. Increase (%) in rice growth[1] parameters at medium and high soil P levels as compared to a low soil P level

Growth parameters	Soil P levels	
	Medium (10.2 kg kg^{-1})	High (87 mg kg^{-1})
Tillers	73	133
Plant height	42	52
Root length	5	5
Dry shoot wt.	229	510
Dry root wt.	84	213

[1] Growth increase = [(growth at med. or high P-growth at low P)/(growth at low P)] × 100.

Rice cultivars/lines responded differently to P application in terms of root and shoot weight. Root weight at low, medium, and high soil P levels varied from 0.24 to 1.22, 0.89 to 2.41, and 1.55 to 4.51 g/3 plants, respectively (data not presented). Similarly, shoot weight varied from 1.45 to 2.39 g at the low P level, 4.14 to 9.29 at the medium P level, and 8.33 to 16.17 at the high P level. From a practical point of view the cultivars which produced well under a low level of P and responded well to added P are the most desirable. Cultivars such as CNA 5164, CNA 4097, CNA 5170, IR 3646-8-1-2, CNA 4137, A8-391 and IAC 47 fall into this category. High shoot growth of these varieties is also asssociated with high root growth. This means that P uptake efficiency may be related to root growth. Extensive root growth under conditions of low P availability in soils might be a genetic characteristic of considerable importance in areas in which soils are low in available P and in which economic constraints limit rates of fertilizer application.

Phosphorus uptake efficiency of the whole plant (roots and shoots) is presented in Table 4. Phos-

Table 4. Phosphorus use efficiency (mg dm/mg P absorbed) in the whole plant (roots and tops) of 25 rice cultivars

Cultivars/Lines	P levels		
	Low	Medium	High
IAC 47	2111bc	1133a	880a–d
Parainaiba	2277bc	1100ab	1033ab
CNA 4194	2193bc	1096ab	871a–d
IREM 257	1957bc	976ab	804a–d
CNA 5619	2031bc	1135a	922a–d
CNA 4140	2173bc	1026ab	896a–d
CNA 4172	2020bc	1037ab	790b–d
IR 3646-8-1-2	2464ab	1168a	909a–d
CNA 4592	1926bc	1066ab	719d
CNA 5170	2110bc	1037ab	849a–d
CNA 5169	2082bc	1037ab	780cd
CNA 4097	1897bc	1079ab	1042a
CNA 4137	1849bc	1032ab	892a–d
CNA 4196	1920bc	961ab	838a–d
CNA 4157	1870bc	980ab	877a–d
CNA 4143	1923bc	974ab	979a–c
CNA 4199	2028bc	972ab	952a–d
CNA 4145	1974bc	952ab	837a–d
GA 4136	1667c	1071ab	859a–d
CNA 4146	1841bc	1012ab	884a–d
CNA 4221	1809bc	936ab	834a–d
CNA 5164	2057bc	964ab	893a–d
CNA 5180	2170bc	893b	864a–d
A8-391	2943a	1144a	831a–d
L81-55	1630c	1018ab	1004a–c

Means in the same column followed by the same letter are not significantly different at $P = 0.05$ by Duncan's Multiple Range Test.

phorus uptake efficiency was highest at the low level of soil P and decreased with increasing soil P levels. This means that, in the classical mode of plant response to increasing nutrient supply, the greatest amounts of dry matter produced per unit of absorbed P were at the lowest level of P supply. As the concentration of P in the growth medium was increased, P uptake increased (Table 2), but less dry matter was produced for each additional unit of absorbed P. Similar results were obtained by Fageria (1974) for P uptake efficiency of rice grown in solution culture. This may be related to P uptake rate.

Phosphorus concentrations in tissue, P-uptake, and P-efficiency ratios (ER-P) were used as independent variables in a step-wise regression to study prediction of growth parameters. Shoot weight was accounted for ($R^2 = 0.98^{**}$) by a combination of root and shoot P concentrations, P-uptake by roots and the ER-P of roots and shoots (Shoot wt = 8.75 − 33.24 P conc. shoot + 5.38 P conc. root + 0.40 P uptake shoot − 0.003 ER − P shoot − 0.0009 ER − P root). Whereas, root weight was best explained by to P concentration in root, P-uptake by shoot and root and ER-P of root (Root wt = 2.53 − 11.43 P conc. root + 0.01 P uptake shoot + 0.47 P uptake root − 0.0008 ER-P root, $R^2 = 0.97^{**}$). Number of tillers was less predictable and related best to P uptake by shoot and root as per the following equation:

Tillers = 4.23 + 0.11 P-uptake shoot + 0.46 P-uptake root, $R^2 = 0.68^{**}$

The regression equation best able to predict plant height was:

Plant height = 96.80 + 43.29 P conc. shoot + 2.20 P uptake root − 0.024 ER − P root, $R^2 = 0.48^{**}$

Conclusions

With the rising cost of P fertilizer, the potential of using nutrient efficient cultivars to increase and/or stabilize crop production becomes increasing attractive. Results of this study indicate that rice cultivars differ significantly in their P requirements. From a practical point of view, the cultivars which produced well under a low level of P and responded well to added P are the most desirable. Cultivars such as CNA 5164, CNA 4097, CNA 5170, IR 3646-8-1-2, CNA 4137, A8-391 and IAC 47 fall into this category. Shoot as well as root dry weight can be used as a criterion for P-screening studies of rice under greenhouse conditions.

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