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Differences in the Performance and Phosphorus-Use Efficiency of Some Tropical Rice (*Oryza sativa* L.) Varieties

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Abstract: Deficiency of phosphorus (P) is widespread in tropical and temperate acid soils. Six rice (*Oryza sativa* L) varieties (TOX 4008 – 34, TOX 3499-84, FARO 51, LOCAL CHECK, FAROX 317, and WAT 107 – TGR) were evaluated for their P nutrition capability at 0, 50, 100, 150 and 200 mg kg^{-1} levels of P applied in an Alfisol. Plant height (from 3 weeks after planting, WAP), number of tillers (from 4 WAP), as well as dry matter (DM) yields, P concentration and uptake in partitioned plant parts and P - use efficiency parameters were estimated after 6 weeks of growth. Plant height at 4 WAP, content and uptake of P determined in shoot and root were significantly ($P < 0.01$) influenced by P application rates. The varieties also differed significantly in their growth; DM production and P - use efficiency, thus permitting their categorization into efficient or non-efficient and responsive or non-responsive types.

Key words: Genotypic differences, phosphorus uptake, P use efficiency, *Oryza sativa*, P application levels

Introduction

Rice production decline may continue despite increased consumption in the last three years. Among the factors of rice production, fertilizers play an important role. Application of phosphoric fertilizer has great impact on crop yield (Nisar *et al.*, 1992; Alaam *et al.*, 2002; Alaam *et al.*, 2003). This is more so on highly weathered and leached soils in tropical and temperate regions of the world where soil acidity causes infertility and is a general limitation to crop production (Von Uexkull and Mutert, 1995). Furthermore, with the global energy crisis, dwindling mineral oil reserves, high P fixation capacity of soils and introduction of fertilizer-responsive high yielding crop varieties have increased the demand of fertilizer materials needed to improve P supply. This has resulted in further burden on small and marginal scale farmers, especially in developing countries.

Several studies (Fageria and Baligar, 1997; Oikeh *et al.*, 2003; Hogh-Jensen and Pedersen, 2003; Kadiata and Lumpungu, 2003) have highlighted the fact that plant species and even varieties within species vary in their behavior to acquire and utilize nutrients for forage dry matter and/or grain production. This property is yet to be fully explored, especially for rice. Identification of rice varieties that can efficiently utilize soil P would assist in improving the yield of the crop on acid, P - deficient soils. Thus, as first step in breeding P - efficient cultivars, it is important to identify P - efficient rice genotypes. The experiment reported here was conducted to evaluate some rice genotypes for P use efficiency.

Materials and Methods

The experiment was conducted in a greenhouse at the University of Ibadan (UI), Nigeria. The experimental soil was loamy sand (0-15 cm) Alfisol (Typic Paleustalf) from UI Teaching and Research farm. Major soil properties included pH (H_2O): 6.2; 14 g C / kg soil organic C; 1.2g N / kg soil; 8.8 mg kg^{-1} extractable P (Bray 1); 0.21 cmol kg^{-1} K; 5.93 cmol kg^{-1} Ca; and 7.89 cmolkg^{-1} effective CEC. Soil analytical methods employed were those described by Juo (1981).

Soil was air-dried, mixed up, and passed through 2-mm sieve and filled into plastic pots up to 4 kg each. Using completely randomized design (CRD) in a factorial arrangement, treatment (replicated three times) consisted of five P levels (0, 50, 100, 150 and 200 mg P kg^{-1}) and six rice genotypes (TOX 4008-34, TOX 3499-84, FARO 51, LOCAL CHECK, FAROX 317, and WAT 107 – TGR). Each kilogram soil also received basal supply of 100 mg N as $(NH_4)_2SO_4$ and 60 mg K as KCl. Four plants were established per pot with soil maintained at 60 % field capacity (FC). Weekly height measurements commenced after 3 weeks while tiller counts were from the 4th week and harvesting was done after 6 weeks. Fresh shoot weights were recorded immediately after harvesting the tops and roots were washed free of soil particles with distilled water. Fresh roots and tops/shoot were oven-dried at 75°C to constant weights, milled and wet-digested using HNO_3 - $HClO_4$ acid mixture (ratio 2:1). The P concentration of digest was determined colorimetrically (Murphy and Riley, 1962) whereas P uptake was estimated by multiplying the concentration by dry matter (DM) produced per pot. All data were analyzed by analysis of variance (ANOVA), using Sigmastat software, and F-test was employed to evaluate the significance of treatments. The student-Newman – Keul's test was used to compare means at both 1 and 5 % probability levels.

Table 1: Significance of F values and orthogonal contrasts derived from analysis of variance (ANOVA) for growth, yield and yield component parameters measured on six rice genotypes at five P levels

Parameter	Rice Genotype (RG)	P-application level (PAL)	RG x PAL interaction	PAL / Parameter Regression		CV (%)
				Linear	Quadratic	
Plant height (cm) at successive growth stages / weeks						
3	**	NS	NS	NS	NS	17.9
4	**	**	NS	NS	*	19.4
Number of tillers at successive growth stages / weeks						
4	**	NS	NS	NS	NS	34.4
5	**	NS	NS	NS	NS	28.2
6	**	NS	NS	NS	NS	33.7
Biomass production (g pot^{-1}) after 6 weeks of growth						
Shoot --Fresh	**	NS	**	NS	NS	35.5
--Dry	**	NS	NS	NS	NS	41.6
Root----Dry	**	NS	NS	NS	NS	82.8
Total biomass	**	NS	*	NS	NS	48.1
Shoot/Root Ratio	**	NS	NS	NS	NS	60.2
Phosphorus nutrition						
Content in shoot	**	**	**	**	**	53.1
Content in root	NS	**	NS	**	**	35.2
Uptake in shoot	**	**	**	**	**	69.0
Uptake in root	**	*	NS	NS	NS	93.3
P use Efficiency	**	**	NS	*	**	74.0

*, ** Indicates significance at 0.05 and 0.01 probability levels, respectively. NS = not significance.

Table 2: Influence of P fertilizer application levels on growth, straw yield and P nutrition parameters across six genotypes of rice

Parameter	P-application level (mg P kg^{-1}) 0	50	100	150	200
Plant height (cm) at 4 weeks	28.0^{b}	31.3^{ab}	30.9^{ab}	30.1^{ab}	34.1^{a}
Shoot dry weight (g pot^{-1})	2.80^{a}	2.82^{a}	3.17^{a}	2.97^{a}	3.26^{a}
Root dry weight (g pot^{-1})	2.24^{a}	2.56^{a}	3.13^{a}	2.25^{a}	2.57^{a}
Shoot/Root ratio	1.63^{a}	1.64^{a}	1.64^{a}	1.83^{a}	2.10^{a}
P conc. in shoot (g kg^{-1})	0.10^{e}	1.90^{d}	3.20^{c}	3.81^{b}	4.71^{a}
P conc. in root (g kg^{-1})	1.02^{b}	1.09^{b}	1.54^{a}	1.62^{a}	1.52^{a}
P uptake in shoot (mg pot^{-1})	2.91^{d}	5.32^{c}	10.04^{b}	11.23^{b}	15.32^{a}
P uptake in root (mg pot^{-1})	2.39^{a}	2.80^{a}	4.43^{a}	3.42^{a}	4.09^{a}
P use Efficiency (mg^{-1})	--	180.21^{a}	133.14^{ab}	94.84^{b}	91.69^{b}

Means for each of the parameters (under different P application levels) that are followed by the same letter are not significantly different at the 0.05 level by the Student-Newman-Keul's method.

Results and Discussion

Effect of P levels on plant height was insignificant (P < 0.05) until the 4th week of growth, indicating sufficiency of nutrient supply during the first 3 weeks of growth (Fig. 1). No difference could be observed in number of tillers throughout the 6 weeks of growth whereas there were significant genotypic differences in both traits (Fig. 2).

Rice genotypes were significantly different in all plant growth and P nutrition parameters, except P concentration in the root, whereas P treatments influenced only plant height at 4 WAP beside the P uptake parameters. Genotypes x P interactions were significant for shoot fresh weight, total biomass (root + shoot) and shoot P uptake. Thus, varietal performance may be specific for particular P level and evaluation under different P application levels may be needed when any of the parameters is used as basis for selection. Except for root P uptake, all P uptake parameters had significant linear relationship with P levels, implying that the trait increased as soil P level increased. Relationship between P levels and plant height at 4 weeks was significant when quadratic regression model was applied. As soil P level was raised, plant height, shoot and root P concentration, and shoot P uptake increased significantly whereas P-use efficiency decreased, indicating the appropriateness of the experimental soil for varietal screening (Fageria, 1989; Fageria and Baligar, 1997).

To evaluate the sensitivity of parameters to P deficiency, increases in plant height, shoot dry weight, shoot–root ratio, shoot P concentration, root P concentration and shoot P uptake at each P addition level compared with 0 mg kg^{-1} P level were estimated (Fig. 3). Among the growth parameters, root dry weight (followed by plant height) exhibited maximum growth increase with P addition. Among P-uptake parameters, shoot P uptake

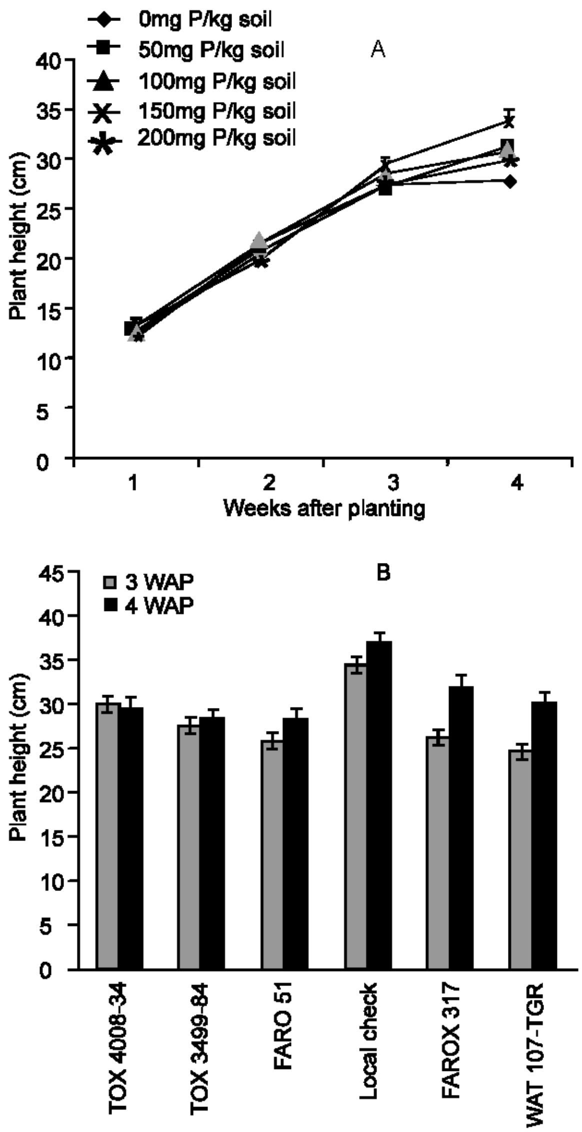

Fig. 1: Effects of (A) phosphorus application levels and (B) genotypic differences on height of rice (*Oryza sativa* L.)

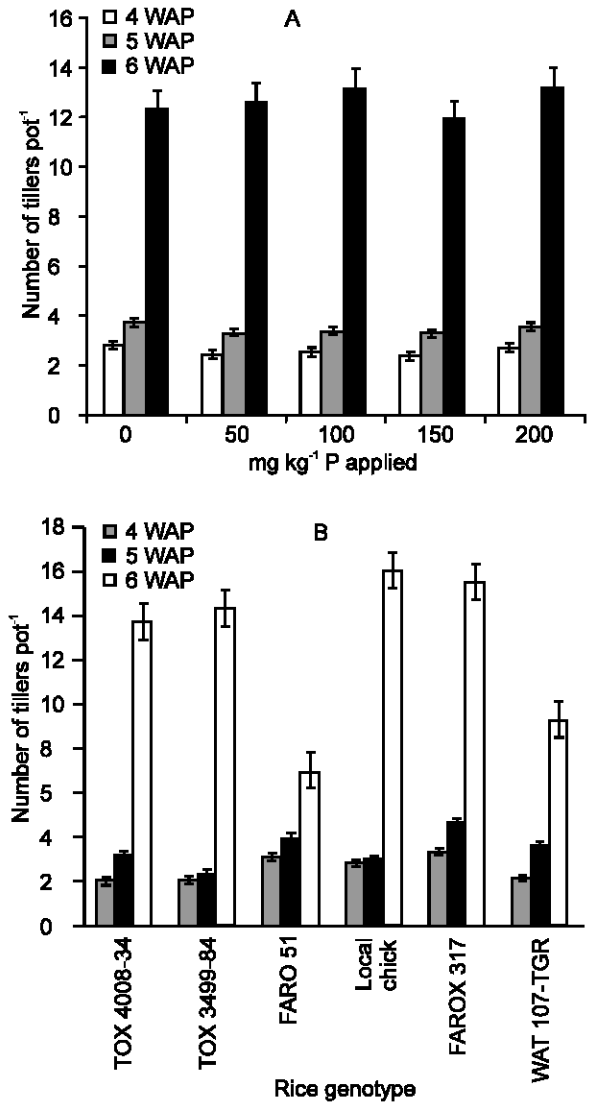

Fig. 2: Effects of (A) phosphorus application levels and (B) genotypic differences on tillering in rice (*Oryza sativa* L.)

(followed by root P uptake) increased maximally. Thus, root dry weight, plant height as well as shoot and root P uptake were the most sensitive parameters of P deficiency. Since plant height is the most easily determined among the parameters, it can be used for screening rice genotypic responses to P.

Genotypic x P interactions for fresh shoot, total biomass, shoot P content and uptake were significant (Table 1), indicating that the P levels caused different responses in growth and P uptake in different genotypes. Except for 200 mg kg^{-1} P level, there were significant ($P < 0.01$) genotypic differences for each P level with respect to plant height measured at 4 WAP (Table 3). Shoot dry weight, however, was significant across but not within P levels. Individual plants of the "local check" variety, on the average, produced significantly more DM at the P levels and were significantly taller than individual plants of the other varieties, with exception at the 0 mg P kg^{-1}. Genotype TOX 4008 – 34 had highest height at 0 mg P kg^{-1}, but interestingly had lower DM even when treated with 50 - 200 mg Pkg^{-1}.

Considering sufficiency P concentration in rice tissue ranges of 1.4-2.7g kg^{-1} DM (Counce and Wells, 1986) it is clear that it was only at the 0 and 50 mg kg^{-1} P levels that shoot P concentration was below the sufficient level. At 100, 150 & 200 mg kg^{-1} levels, plant P concentrations were above the critical, indicating that P concentration limited rice DM production only at low P levels.

Table 3: Plant height and shoot dry weight of six rice genotypes treated with different phosphorus application levels

Rice genotype								
P level (mg kg^{-1})	TOX 4008-34	TOX 3499-84	FARO 51	Local Check	FAROX 317	WAT 107-TGR	F-test	CV (%)
Plant height (cm) at 4 weeks of growth								
0	31.6^{a}	26.3^{a}	25.5^{a}	30.1^{b}	26.4^{a}	28.2^{a}	**	3.9
50	27.5^{a}	27.1^{a}	32.0^{a}	33.7^{b}	35.5^{a}	32.3^{a}	**	3.5
100	25.8^{a}	29.9^{a}	22.6^{a}	41.0^{ab}	31.3^{a}	34.6^{a}	**	3.6
150	28.5^{a}	25.8^{a}	28.6^{a}	37.3^{ab}	34.5^{a}	25.7^{a}	**	3.7
200	34.0^{a}	32.4^{a}	32.5^{a}	42.7^{a}	32.6^{a}	30.2^{a}	NS	3.2
Average	29.46^{b}	28.28^{b}	28.25^{b}	36.97^{a}	32.04^{b}	30.19^{b}	**	3.6
Shoot dry weight (g pot^{-1})								
0	1.57^{a}	1.40^{a}	3.40^{a}	4.73^{a}	3.03^{a}	2.90^{a}	NS	5.8
50	1.37^{a}	1.97^{a}	3.67^{a}	4.10^{a}	3.30^{a}	2.53^{a}	NS	5.8
100	1.23^{a}	3.00^{a}	2.77^{a}	5.27^{a}	3.73^{a}	3.00^{a}	NS	5.2
150	1.13^{a}	2.17^{a}	4.13^{a}	4.77^{a}	3.20^{a}	2.40^{a}	NS	5.6
200	2.07^{a}	2.70^{a}	4.20^{a}	4.50^{a}	3.70^{a}	2.40^{a}	NS	5.1
Average	1.47^{d}	2.25^{c}	3.63^{b}	4.67^{a}	3.39^{b}	2.65^{c}	**	5.5

**Significant at 0.01 probability level, NS = not significant.

Means for each of the parameters (under different rice varieties) that are followed by the same letter are not significantly different at the 0.05 level by the Student-Newman-Keul's method.

Table 4: Root dry weight, total biomass, shoot-root ratio, as well as P concentration and uptake in root and shoot six rice genotypes

Genotype				P-concentration (g kg^{-1})		P-uptake (mg pot^{-1})	
	Root dry Weight (g pot^{-1})	Total biomass (g pot^{-1})	Shoot-root ratio	Root	Shoot	Root	Shoot
TOX4008-34	1.02^{b}	2.49^{d}	1.88^{a}	1.23^{a}	2.68^{d}	1.15^{b}	4.04^{c}
TOX3499-84	1.07^{b}	3.32^{d}	2.33^{a}	1.36^{a}	2.13^{e}	1.51^{b}	5.09^{c}
FARO 51	1.75^{b}	5.39^{c}	2.15^{a}	1.43^{a}	2.50^{c}	2.60^{b}	9.27^{b}
LOCAL CHECK	1.87^{b}	6.55^{b}	2.57^{a}	1.45^{a}	2.82^{c}	2.76^{b}	13.18^{a}
FAROX 317	5.09^{a}	8.48^{a}	0.89^{b}	1.29^{a}	3.49^{b}	6.54^{a}	12.21^{a}
WAT 107-TGR	4.34^{ab}	6.99^{b}	0.77^{b}	1.40^{a}	3.91^{a}	5.98^{a}	9.99^{b}
F-test	**	**	**	NS	**	**	**
CV (%)	13.2	7.1	11.1	7.3	4.0	16.7	6.9

** Significant at 0.01 probability level, NS = not significant. Means in the same column followed by the same letter are not significantly different at 0.05 probability level by Student-Newman-Keul's method.

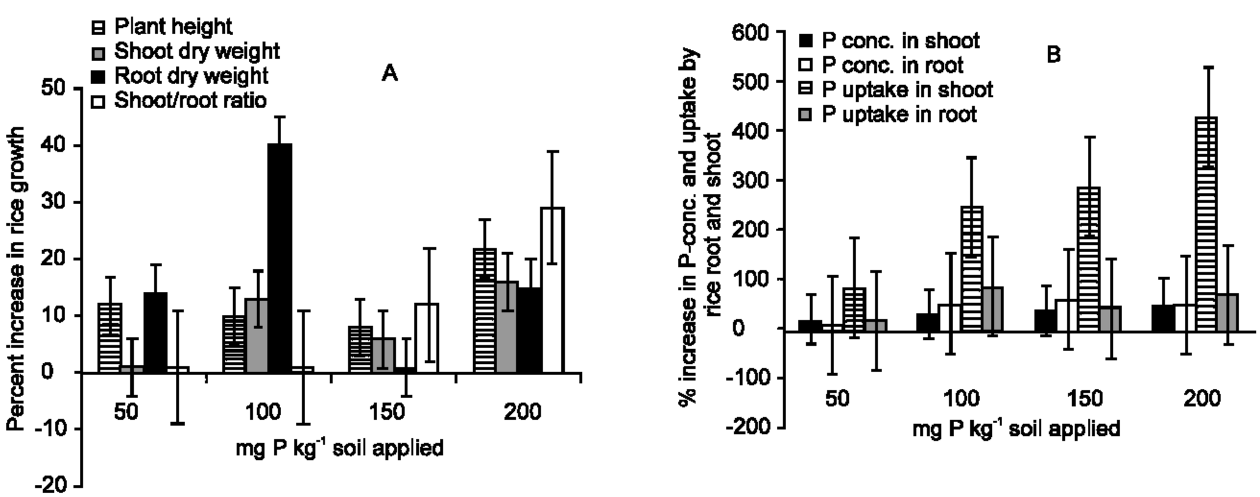

Fig. 3: Percentage increase in: (A) growth and (B) phosphorus uptake parameters of rice at the various phosphorus addition levels. [% increase = (growth or P nutrition parameter value at specific P application level - growth or P nutrition value at 0mg kg-1 / growth or P nutrition parameter value at 0mg kg^{-1}) x 100].

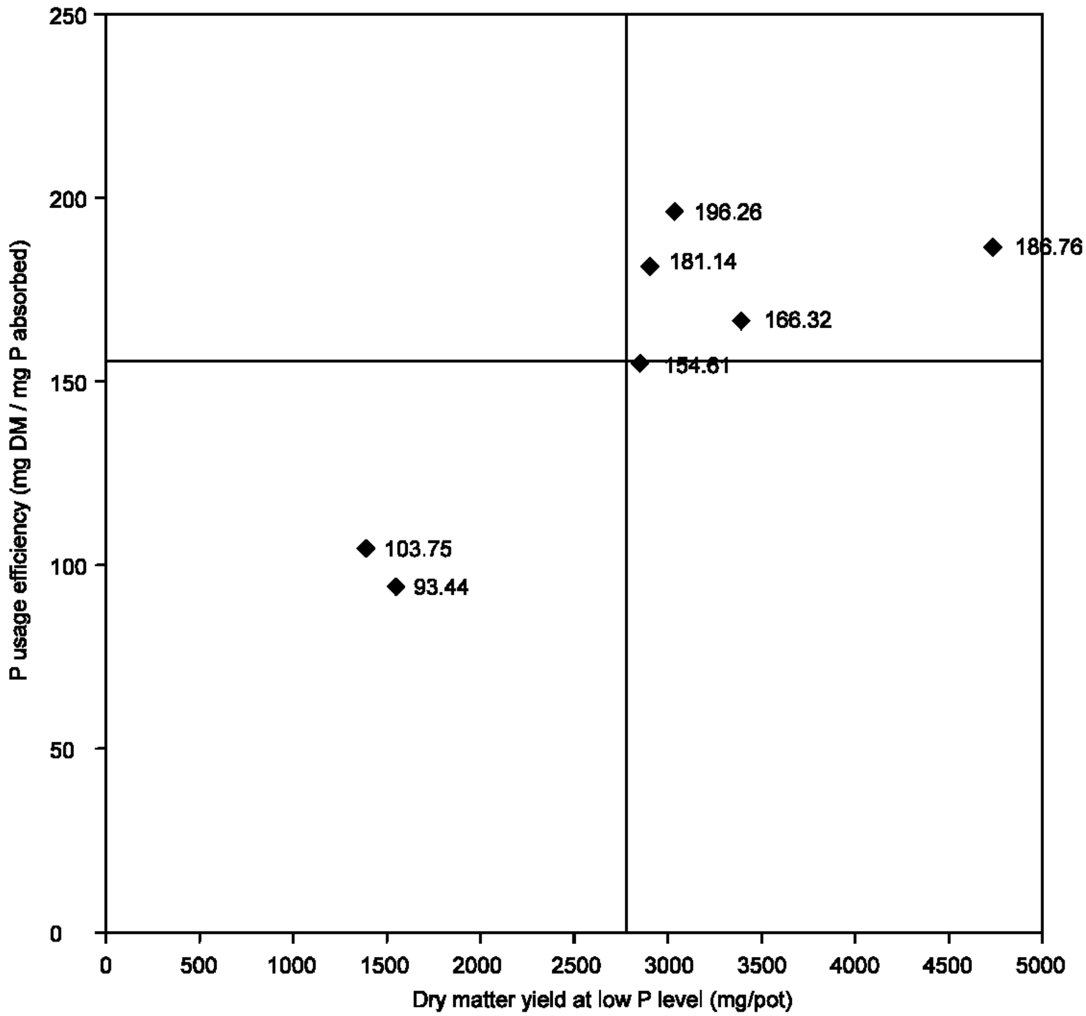

Fig. 4: Categorization of the six rice genotypes on the basis of phosphorus use efficiency. [The indicated values represent the actual P-use efficiency by each cultivar as plotted against the respective total biomass (dry root + dry shoot) produced. The value in circle is the overall average P-use efficiency for all the cultivars plotted against the average total biomass used in demarcating the categories].

Table 5: Phosphorus uptake in the shoot and P use efficiency of six rice genotypes as influenced by different P application levels

Rice Genotype	P uptake (mg pot^{-1}) in shoot 0	50	100	150	200	Average across application levels	P use efficiency (mg^{-1})
TOX4008-34	1.28^{b}	1.96^{b}	3.94^{b}	3.68^{b}	9.35^{a}	4.04^{c}	93.44^{c}
TOX3499-84	1.52^{c}	2.88^{bc}	4.96^{a}	6.93^{ab}	9.16^{a}	5.09^{c}	103.75^{b}
FARO 51	2.90^{d}	3.91^{d}	8.56^{c}	12.75^{b}	18.23^{a}	9.27^{b}	166.32^{a}
LOCAL CHECK	4.59^{c}	7.40^{c}	15.48^{b}	17.29^{ab}	21.16^{a}	13.18^{a}	186.76^{ab}
FAOX317	3.29^{d}	8.20^{c}	15.22^{b}	13.92^{b}	20.44^{a}	12.21^{a}	196.26^{a}
WAT 107-TGR	3.88^{c}	7.58^{c}	12.06^{b}	12.81^{b}	13.61^{a}	9.99^{b}	181.14^{ab}
F-test	**	**	**	**	**	**	**
CV (%)	19.5	10.7	5.6	5.0	3.7	8.9	14.9

** Significant at 0.01 probability level, NS = not significant.

Means in the same column followed by the same letter are not significantly different at 0.05 probability level by Student-Newman-Keul's method. P use efficiency = (dry matter yield of root and shoot across 50-200 mg P kg^{-1} level - dry matter of root and shoot at 0mg P kg^{-1} level) / (P accumulation in root and shoot across 50-200 mg P kg^{-1} level - P accumulation in root and shoot at 0mg P kg^{-1} level)

As estimated from DM, P-uptake under the P application levels differed among genotypes (Table 5). P-use efficiency (PUE) also differed among genotypes across P levels (Table 5), with FAROX 317 having the highest whereas TOX 4008–34 had the lowest. Using total biomass production with 0 P and genotypes PUE, the tested genotypes fitted into two categories (Fig. 4) (Fageria and Baligar, 1997):

Efficient and responsive genotypes (FARO 51, LOCAL CHECK, FAROX 317, and WAT 107-TGR) that produced DM yield (@ 0 P) higher than average for all genotypes considered besides responding well to P addition to the extent that PUE was higher than average for the genotypes.

Non-efficient but responsive genotypes (TOX 4008 – 34 and TOX 3499-84) that produced less than average DM yields but PUE higher than average for tested varieties. Efficient but non-responsive genotypes should produce higher than average DM yield and have average PUE lower than average obtained for all genotypes tested. None of the six genotypes used in this study fall into this group. Similarly, none of the six varieties could be classified as "Non-efficient and non responsive". Such genotypes should produce lower than average DM yield and have lower than average PUE. Efficient and responsive genotypes are best as they can produce well at low P level apart from responding well when P is supplied (Fageria and Baligar, 1997). The second category can also produce well and can be recommended for production in low technology regions or under low P level, as they are efficient DM producers, their main defect being that they cannot respond well to P fertilization.

Conclusion: Basing the screening of crop varieties on their nutrient use efficiencies has been prompted by increasing fertilizer costs, inability of small and medium scale farmers to have ready access to fertilizers and environmental contamination / pollution possibilities. Since rice genotypes are "certified" to have different P requirements, PUE (dry matter production per unit of P uptake) can be used in P screening studies of the crop under greenhouse conditions.

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