DIFFERENCES IN PHOSPHORUS ABSORPTION, TRANSPORT AND UTILIZATION BY TWENTY RICE (*ORYZA SATIVA* L.) CULTIVARS

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Plants have adopted a wide range of morphological and physiological mechanisms to cope with P deficiency in soil. Crop species and even cultivars within the species differ genetically in these mechanisms and hence in their response to P deficiency stress. We evaluated growth response and P utilization efficiency of twenty rice cultivars grown in hydroponics with adequate (260 µ*M* P) as well as deficient (26 µ*M* P) levels of P. The cultivars differed significantly ($p<0.001$) in biomass accumulation at both P levels. Phosphorus contents varied significantly ($P<0.01$) among rice cultivars at both levels of P supply. Positive correlation ($p< 0.01$) of shoot dry matter production in rice cultivars with root biomass ($r = 0.70$, n=160), P uptake ($r = 0.82$, n=160) and utilization rate ($r = 0.46$, n=160) indicated that these are the main morphological and physiological parameters for maximizing shoot production in P-starved condition. Greater efficiency in dry matter production per unit amount of P absorbed was obvious in IR 24-PK, 77-74-5-2 and PK 3362-2-1, whereas 33897-11, PK 1818-4-1-7 were least efficient in terms of specific utilization rate of P.

Keywords: Genetic variability, P use efficiency, P utilization rate, rice

INTRODUCTION

Phosphorus (P) is the second limiting nutrient for crop production after N; and >30% of the world's arable land is deficient in available P (Vance, *et al.,* 2003). Notoriously low use-efficiency (15-20 %) of native soil P, sub-optimal rates of P application in tropics and subtropics (Vance, *et al.,* 2003) and fear of depletion of world's resources of inexpensive rock P, demands to development or adoption of strategies aimed at increased P acquisition and utilization efficiency by plants.

Plants have evolved a diverse array of strategies to obtain adequate P under conditions of limited P supply. These strategies can be grouped into two broad categories. First are those aiming at increased P acquisition from soil and second aimed at increased P utilization within the plants. These includes decreased growth rate, increased growth per unit of P uptake, remobilization of internal P (Vance, *et al.,* 2003; Vance, 2001; Plaxton and Carswell, 1999), increased production and secretion of phosphatases, exudation of organic acids (Raghothama, 1999) and increased root surface area due to more root growth, etc. (Lynch and Brown, 2001). Species and cultivars within species differ greatly in adopting these strategies as most of these processes are under genetic control. Exploitation of plant genetic capacity to produce cultivars efficient in P acquisition and utilization would sustain agriculture in developing countries. Identification of traits/ mechanisms responsible for these differences is a prerequisite for long term breeding experiments.

Rice is a major cereal crop grown around the globe and is an important staple food in Pakistan. It commonly suffers from P deficiency, because >90% soils of the country are deficient in available P. Furthermore, farmers are generally reluctant to apply P fertilizers because of high price, lack of availability and low recovery efficiency. Hence there is a dire need to categorize existing rice cultivars according to their P use efficiency to sustain rice production in the country and for long term breeding experiments to produce more P efficient rice cultivars. We evaluated twenty rice cultivars for their growth, P uptake and P utilization efficiency under deficient and adequate P levels in hydroponics for their categorization according to P use efficiency.

MATERIALS AND METHODS

The experiment was conducted in a green-house of Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. Seeds of 20 rice cultivars were germinated in pre-washed riverbed sand in polyethylene lined iron trays. Fifteen days old seedlings were transplanted in foam plugged holes of thermopol sheets, floating on Yoshida nutrient solution (Yoshida *et al.,* 1976) containing 26 and 260 µ*M* P in two polythene lined iron tubs of 200-L capacity. The pH of the solution was maintained daily at 6.0 ± 0.5 with 0.05 *M* HCl or NaOH. The experiment was laid out according to completely randomized factorial design (Steel *et al.,* 1996) with eight replicates of each cultivar, consisting of two plants per replicate. The plants were harvested 20 and 32 days after transplanting. The nutrient solution was changed after the first harvest. At each harvest the plants were thoroughly washed with distilled water, blotted dry with tissue papers and separated into roots and shoots. Washed samples were dried at 70º C to a constant weight in a forced-air driven oven for 48 h. Dried plant samples were weighed and ground to 40-mesh. A 0.25-g portion of ground samples was digested in di-acid mixture of perchloric and nitric acid (3:1) (Miller, 1998). Phosphorus concentration in plant digest was estimated by vanadomolybdate yellow color method (Chapman, 1961) using UV-Visible spectrophotometer. Different calculations made were as following.

1. Relative growth rate

Relative growth rate (RGR) of shoot and root (mg g^{-1} day^{-1}) was calculated as

$$RGR = \frac{\ln W_2 - \ln W_1}{\Delta T} \qquad \text{(Hunt, 1978)}$$

Whereas W_1 and W_2 are the shoot or root dry weight (g) at harvest time T_1 and T_2 (day), respectively and $\triangle T$ is the time interval between two harvests (days).

2. Specific absorption rate

Specific absorption rate (SAR) of P was calculated (μ*M* P g^{-1} RDM day^{-1}) as

$$SAR = \frac{P_2 - P_1}{R_2 - R_1} \times RGR\,(root) \qquad \text{(Hunt, 1978)}$$

Where P_1 and P_2 are total P uptake at harvest 1 and 2, respectively and R_1 and R_2 are root dry weight at first and second harvest, respectively and RGR (root) is relative growth rate of root.

3. Specific utilization rate

Specific utilization rate (SUR) of P (mg DW mg^{-1} P day^{-1}) for various cultivars was calculated as

$$SUR = \frac{TDW_2 - TDW_1}{T_2 - T_1} \times \frac{\ln P_2 - \ln P_1}{P_2 - P_1} \qquad \text{(Hunt, 1978)}$$

Where TDW is total dry weight, and P and T were same as in preceding calculations.

4. Phosphorus transport rate

Phosphorus transport rate (PTR) was calculated on the basis of shoot dry matter (SDM) as μM P g^{-1} SDM day^{-1} using following formula:

$$PTR = \frac{P_2 - P_1}{S_2 - S_1} \times RGR\,(shoot) \qquad \text{(Pitman, 1972)}$$

Where P_1 and P_2 is P uptake in shoot, S_1 and S_2 are SDM at first and second harvest, respectively and RGR (shoot) is relative growth rate of shoot.

5. Phosphorus utilization index

Phosphorus utilization index (PUI) of various rice cultivars was calculated according to Siddiqui and Glass (1991) as given below:

$$PUI = \frac{1}{P\ Conc.\ (mg\ g^{-1})} \times \text{Shoot dry matter } (g\ plant^{-1})$$

The data was assessed statistically using software MSTAT-C (Russel and Eisensmith, 1983).

RESULTS

Plants were harvested twice to facilitate calculations of rate related parameters; therefore, all other data reported pertain to second harvest only.

Biomass Production

The cultivars differed significantly (P<0.01) in shoot dry matter (SDM), root dry matter (RDM), and root: shoot ratio (RSR) at both levels of P supply (Table 1). Shoot dry matter production by rice cultivars was decreased 2 folds when P supply was reduced from 260 to 26 μ*M* in growth medium. It ranged between 0.82 and 1.88 g/plant. Relative SDM production by cultivars in P deficient level compared to control, differed significantly among cultivars and was maximum in Bas-385-386 and minimum in Jhuna 349. Phosphorus deficiency reduced root dry matter production significantly and it ranged between 0.32 and 0.94 g/plant at deficient level of P supply. Root shoot ratio was 2 folds higher in plants deficient in P compared to control. Maximum RSR was observed in Jhuna 349 and minimum was observed in 49732 at deficient P level. Relative growth rate of shoots and roots varied among cultivars at both levels of P supply and was higher under P deficient conditions (Table 1). Relative growth rate of shoot ranged between 30 and 128 mg g^{-1} day^{-1} and relative growth rate of root ranged between 62 and 129 mg g^{-1} day^{-1} at deficient level of P supply.

Physiological parameters

Various rice cultivars and rate of P supply had a significant (P<0.01) main and interactive effect on concentration and uptake of P in shoot and root of rice cultivars (Table 2). Phosphorus concentration increased 6 folds in shoot and 7 folds in root, as the P supply was increased from 26 to 260 μ*M* in the growth medium. Plant grown at 26 μ*M* P had P concentration lower than the critical lower limit of sufficiency (4-8 mg g^{-1}) at this ontogenetic stage. P concentration in rice shoots ranged between 1.00 and 2.98 mg g^{-1} under P deficient treatment and between 5.76 and 10.25 mg g^{-1} under adequate P supply. As expected, shoot and root P uptake was lower in plants grown with deficient

Table 1. Shoot and root dry matter, root: shoot ratio, relative growth rate of shoot and root of rice genotypes grown at adequate and deficient P levels

GENOTYPES	Shoot dry matter (g plant^{-1})		Root dry matter (g plant^{-1})		Root: shoot ratio		Relative Growth Rate of Shoot (mg g^{-1} day^{-1})		Relative Growth Rate of Root (mg g^{-1} day^{-1})	
	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate
1053-1-2	1.39 c	2.55 c	0.66 bc	0.58 c	0.47 ab	0.23 cd	94 b	72 c	127 ab	72 c
3320-31-2	1.88 a	3.45 a	0.94 a	0.93 a	0.50 a	0.27 c	96 b	78 c	136 ab	110 ab
33897-11	0.82 e	1.77 d	0.38 e	0.51 cd	0.46 ab	0.29 bc	81 c	38 e	72 bc	60 d
35/88	1.11 ef	2.02 d	0.48 d	0.63 bc	0.43 b	0.31 b	85 bc	61 d	100 b	84 b
43175	1.63 b	1.74 d	0.80 a	0.72 bc	0.49 ab	0.41 a	86 bc	85 bc	129 ab	105 ab
4321	1.09 e	1.59 de	0.59 c	0.59 c	0.54 a	0.37 a	68 c	53 de	94 b	85 b
49732	1.44 c	2.09 d	0.41 d	0.49 d	0.28 e	0.23 cd	100 b	42 e	111 ab	55 de
74/88	1.52 bc	2.17 d	0.66 bc	0.47 c	0.43 b	0.22 cd	103 b	109 ab	128 ab	104 a
Bas-385-244	1.35 cd	2.24 cd	0.42 d	0.57 c	0.31 e	0.25 c	30 d	67 cd	113 ab	95 b
Bas-385-386	1.51 bc	1.69 de	0.43 d	0.51 cd	0.28 e	0.30 c	104 ab	77 c	118 ab	78 bc
BR-652-149-1-3	1.03 e	2.04 d	0.55 c	0.51 c	0.53 a	0.25 c	96 b	91 b	137 ab	88 b
IR 24,PK 77-74-5-2	1.42 c	2.46 c	0.63 bc	0.83 b	0.44 b	0.34 b	109 ab	110 ab	117 ab	123 a
Jhuna 349	1.26 d	3.67a	0.68 bc	1.07 a	0.54 a	0.29 c	108 ab	110 ab	103 ab	109 ab
Jhuna 349XBas 370	1.11 e	2.79 bc	0.45 d	0.79 b	0.41 b	0.28 c	47 cd	94 b	62 c	100 ab
Jhuna 349XBas 385	1.33 d	2.91 b	0.47 d	0.82 b	0.35 c	0.28 c	95 b	77 c	95 b	118 a
PK 1818-4-1-7	1.79 ab	2.71 bc	0.67 bc	0.78 b	0.37 c	0.29 c	62 c	74 c	78 bc	108 ab
PK 2981-8-1	1.86 a	3.05 ab	0.75 b	0.88 ab	0.40 b	0.29 c	112 ab	80 bc	127 ab	109 ab
PK 3250-4-1-2-1	1.18 d	2.06 d	0.32 e	0.40 d	0.27 d	0.19 d	128 a	133 a	158 a	120 a
PK 3303-7-2	1.54 bc	2.86 b	0.56 c	0.68 bc	0.36 c	0.24 c	96 b	72 c	119 ab	87 b
PK 3362-2-1	1.87 a	3.45 a	0.75 b	0.86 ab	0.40 b	0.25 c	111 a	96 b	140 a	121 a

Note: Values are means of 8 replicates. Means followed by same letters are statistically similar at 95% probability level.

Table 2. Concentration and contents of P in shoot & root of rice genotypes grown at adequate and deficient P levels

GENOTYPES	Shoot P concentration (mg g^{-1})		Shoot P contents (mg plant^{-1})		Root P concentration (mg g^{-1})		Root P contents (mg plant^{-1})	
	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate
1053-1-2	1.03 d	9.29 a	1.40 c	23.05 ab	0.56 c	3.60 b	0.37 bc	2.09 c
3320-31-2	1.35 cd	8.11 b	2.55 b	27.68 a	0.50 c	3.18 b	0.47 b	2.96 ab
33897-11	1.04 d	9.94 a	0.84 d	17.68 bc	1.03 a	3.22 b	0.39 bc	1.64 cd
35/88	1.48 c	8.46 ab	1.65 c	20.51 b	0.65 bc	4.21 ab	0.31 c	2.65 b
43175	1.33 cd	10.25 a	2.17 b	24.35 ab	0.60 bc	3.28 b	0.48 b	2.36 bc
4321	2.98 a	9.06 ab	1.08 d	14.03 c	0.47 c	2.32 c	0.28 c	1.37 d
49732	1.76 b	8.61 ab	2.54 b	20.50 b	0.76 b	2.53 c	0.31 c	1.24 d
74/88	1.44 c	8.07 b	2.09 bc	15.81 c	0.38 cd	4.85 a	0.25 c	2.28 bc
Bas-385-244	1.41 c	8.50 ab	1.92 bc	19.01 b	0.50 c	2.79 bc	0.21 cd	1.59 d
Bas-385-386	1.01d	10.28 a	1.52 c	17.09 bc	0.42 cd	3.55 b	0.18 d	1.81 c
BR-652-149-1-3	1.70 b	8.47 ab	1.76 bc	16.11 c	0.33 d	4.71 a	0.18 d	2.40 bc
IR 24,PK 77-74-5-2	1.05 d	6.84 bc	1.45 c	16.79 bc	0.30 d	3.05 b	0.19 d	2.53 b
Jhuna 349	1.49 c	5.76 c	1.89 bc	21.21 ab	0.41 cd	1.85 d	0.28 c	1.98 c
Jhuna 349XBas 370	1.40 c	7.71 b	1.54 c	21.41 ab	0.36 cd	2.29 c	0.16 d	1.81 c
Jhuna 349XBas 385	1.46 c	5.98 c	1.88 bc	18.01 b	0.49 c	4.35 ab	0.23 cd	3.57 a
PK 1818-4-1-7	1.46 c	9.96 a	2.61 b	27.04 a	0.49 c	2.81 bc	0.33 c	2.19 bc
PK 2981-8-1	1.76 b	6.55 bc	3.25 a	19.81 b	1.00 a	2.92 bv	0.75 a	2.57 b
PK 3250-4-1-2-1	1.54 c	6.72 bc	1.52 c	12.08 c	0.41 cd	2.05 cd	0.13 d	0.82 de
PK 3303-7-2	1.45 c	7.80 b	2.20 b	22.01 ab	0.61 bc	2.04 cd	0.34 c	1.39 d
PK 3362-2-1	1.22 cd	6.62 bc	2.29 b	22.90 ab	0.29 d	2.20 cd	0.22 cd	1.89 c

Note: Values are means of 8 replicates. Means followed by same letters are statistically similar at 95% probability level.

Table 3. Specific absorption, transport, and utilization rates of P and P Utilization index of rice genotypes grown at adequate and deficient P levels

GENOTYPES	Specific absorption rate (µ *MP* g^{-1} RDM day^{-1})		Phosphorus transport rate (µ *MP* g^{-1} SDM day^{-1})		Specific utilization rate (µ *MP* g^{-1} DM day^{-1})		P Utilization Index (g TDM mg^{-1} P)	
	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate
1053-1-2	8.18 cd	85 cd	2.65 ef	1.39 ab	0.27	17.85 bc	98 ab	7.0 d
3320-31-2	12.07 c	93 c	4.8 d	1.39 ab	0.43 c	21.61 b	110 a	12.6 b
33897-11	4.80 d	77 d	2.96 ef	0.79 bc	0.18 de	17.11 bc	64 cd	5.4 de
35/88	12.2 c	90 c	5.1 c	0.75 bc	0.24 d	23.03 b	71 c	7.6 d
43175	11.11 c	111 b	3.78 de	1.23 ab	0.17 de	28.58 ab	91 b	9.0 c
4321	5.77 d	44 e	2.56 ef	0.37 d	0.18 de	13.71 c	84 bc	7.0 d
49732	26.20 a	106 b	7.72 ab	0.82 bc	0.24 d	19.22 b	74 c	6.4 d
74/88	14.38 bc	131 a	5.51 bc	1.06 b	0.27 d	27.95 ab	104 a	13.8 b
Bas-385-244	20.59 b	130 a	1.90 f	0.96 b	0.26 d	26.42 ab	100 ab	13.2 b
Bas-385-386	14.28 bc	139 a	3.38 e	1.51 a	0.16 de	36.75 a	104 a	11.0 bc
BR-652-149-1-3	14.71 bc	103 b	6.33 b	0.61 c	0.24 d	24.50 ab	92 b	11.8 bc
IR 24,PK 77-74-5-2	8.02 cd	75 d	3.58 e	1.35 ab	0.36 cd	21.95 b	111 a	16.8 ab
Jhuna 349	11.11 c	67 de	6.18 b	0.85 bc	0.64 a	16.76 bc	92 b	19.0 a
Jhuna 349XBas 370	7.57 cd	92 c	3.29 e	0.79 bc	0.36 cd	25.30 ab	59 d	13.4 b
Jhuna 349XBas 385	14.37 bc	67 de	5.78 bc	0.91 b	0.49 bc	11.77 c	95 ab	12.8 b
PK 1818-4-1-7	11.51 c	111 b	4.05 d	1.23 ab	0.27 d	23.34 b	59 d	9.2 c
PK 2981-8-1	22.67 ab	88 cd	7.91 ab	1.06 b	0.47 bc	14.48 c	91 b	11.2 bc
PK 3250-4-1-2-1	23.34 ab	127 a	8.85 a	0.77 bc	0.31 d	26.7 ab	48 de	20.0 a
PK 3303-7-2	19.02 ab	92 c	5.62 bc	1.06 b	0.37 cd	19.37 b	102 a	11.2 bc
PK 3362-2-1	16.47 bc	95 c	5.15 c	1.53 a	0.52 b	24.61 ab	107 a	17.2 a

Note: Values are means of 8 replicates. Means followed by same letters are statistically similar at 95% probability level.

levels of P supply compared to control. Maximum shoot P uptake was exhibited by PK 2981-8-1 and it ranged between 0.84 and 3.25 mg plant^{-1} at deficient P supply and was about 18 folds lower than those at adequate P supply. There were significant main and interactive effects of cultivars and rate of P supply on specific absorption rate (SAR), phosphorus transport rate (PTR), specific utilization rate (SUR) and phosphorus utilization index (PUI) (Table 3). Specific absorption rate and PTR reduced significantly in all of cultivars when P supply was reduced in growth medium. However, phosphorus utilization rate (PUR) and PUI increased significantly with P deficiency in growth medium. SAR ranged between 4.8 and 26.2 µ*M* P g^{-1} RDM day^{-1}at deficient P supply and was maximum in PK 3250-4-1-2-1. Phosphorus transport rate was ranged from 1.9 to 7.91 µ*M* P g^{-1} SDM day^{-1} and was also higher in PK 3250-4-1-2-1. Specific utilization rate varied significantly at both levels of P supply and was lower in PK 3250-4-1-2-1.

DISCUSSION

Shoot dry matter production is generally used as a selection criterion for evaluating cultivars for nutrient efficiency at seedling stage (Ahmad *et al.,* 1992). Variable SDM production and significant phosphorus x cultivar (PXC) interaction (Table 1) clearly suggested differential growth response of cultivars to varying P supply. These significant interactions between cultivars and rate of nutrient supply are important for crop cultivar development (Kang, 1998). Positive correlation of SDM production in P deficient supply, with RDM (r = 0.70), P uptake (r = 0.82) and P utilization rate (r = 0.46) (Table 4) indicated that these are the main morphological and physiological parameters for maximizing SDM production in P-starved condition. Percent reduction in SDM production (PSF %) differed highly significantly (P<0.01) among 20 rice cultivars (Fig.1) but it could not explain the differences in P utilization index among rice cultivars. On the basis of improvement in SDM production at adequate P levels and their relative performance at P stress level, Jhuna 349 may be termed as the cultivar most responsive to P application followed by 3320-31-2 and PK 2981-8-1.

In this study, rate of P supply influenced biomass portioning between shoot and root and increased RSR two fold as the P supply was reduced in the growth medium. Root size/weight is of greater significance in determining the amount of P absorbed (Caradus, 1995) while increased translocation of photosynthates from shoot to root under P deficiency increases RSR (Gaume *et al.,* 2001, Kosar *et al.,* 2003). At deficient level of P, SDM contributed 65-78 percent to total biomass while at adequate P, 71-82 percent biomass was contributed by shoot. The differences among cultivars for increase in RSR were significant (p<0.01) at deficient P supply (Table 1), a phenomenon well documented in P starved plants (Ahmad *et al.,* 2001). Significant negative correlation between RSR and SAR (r = 0.59, n = 160) was attributed to increased SDM production with increasing SAR of P. Highly significant and positive correlation between RGRS and PTR indicates that cultivars with higher PTR exhibited higher shoot growth rate in the P deficient conditions.

Plants having ability to take up P at very low concentrations of P ions in the soil solution would have a definitive advantage for P acquisition efficiency (Ahmad *et al.,* 2001). Phosphorus uptake was significantly lower in P starved plants compared to control and it was highly correlated with SDM and RDM production. Root dry matter of rice cultivars has significant and positive correlation with shoot (r = 0.53, n = 160) and root (r = 0.46, n = 160) P uptake and specific utilization rate (r = 0.46, n = 160) indicating that uptake and utilization of P dominates in roots of P starved plants. Cultivars capable of efficiently re-translocating P from inactive to metabolically active sites (roots) under P-limiting conditions can better tolerate low P in the root environment. Of the total P uptake, 64-90 % P in rice plants was accumulated by shoot. These differences in nutrient uptake and transport rate may be due both to increased ion transfer from steel to xylem and long distance transport under nutrient deficiency stress (Salinas, and Sanchez, 1976), and are important for breeding/selection of nutrient efficient cultivars. Mean SUR of rice cultivars decreased about 7-fold with an increase in P supply in the root medium. Greater efficiency in dry matter production per unit amount of P absorbed was obvious in IR 24-PK, 77-74-5-2 and PK 3362-2-1, whereas 33897-11, PK 1818-4-1-7 were less efficient in terms of SUR of P. Significant and positive correlation among SUR with SDM (r=0.46, n=160) indicates that cultivars better in SUR, accumulated higher biomass at deficient P level.

Phosphorus utilization index (PUI) of rice cultivars differed significantly at both levels of P supply; a higher PUE at deficient P level was related to more biomass production per unit of P absorbed. We grouped these cultivars into four categories (Fig. 2) by plotting their total dry matter (TDM) production against P utilization efficiency, viz. efficient and responsive (ER), efficient but non-responsive (ENR), non-efficient but responsive (NER) and non-efficient and non-responsive (NENR) (Fageria and Baligar, 1993; Kosar *et al.,.,* 2003). Six cultivars (IR-24 PK 77-74; 1053-1-2; Jhuna 349XBas 370; PK 3382-2-1; Jhuna 349 and 3320-31-2) can be

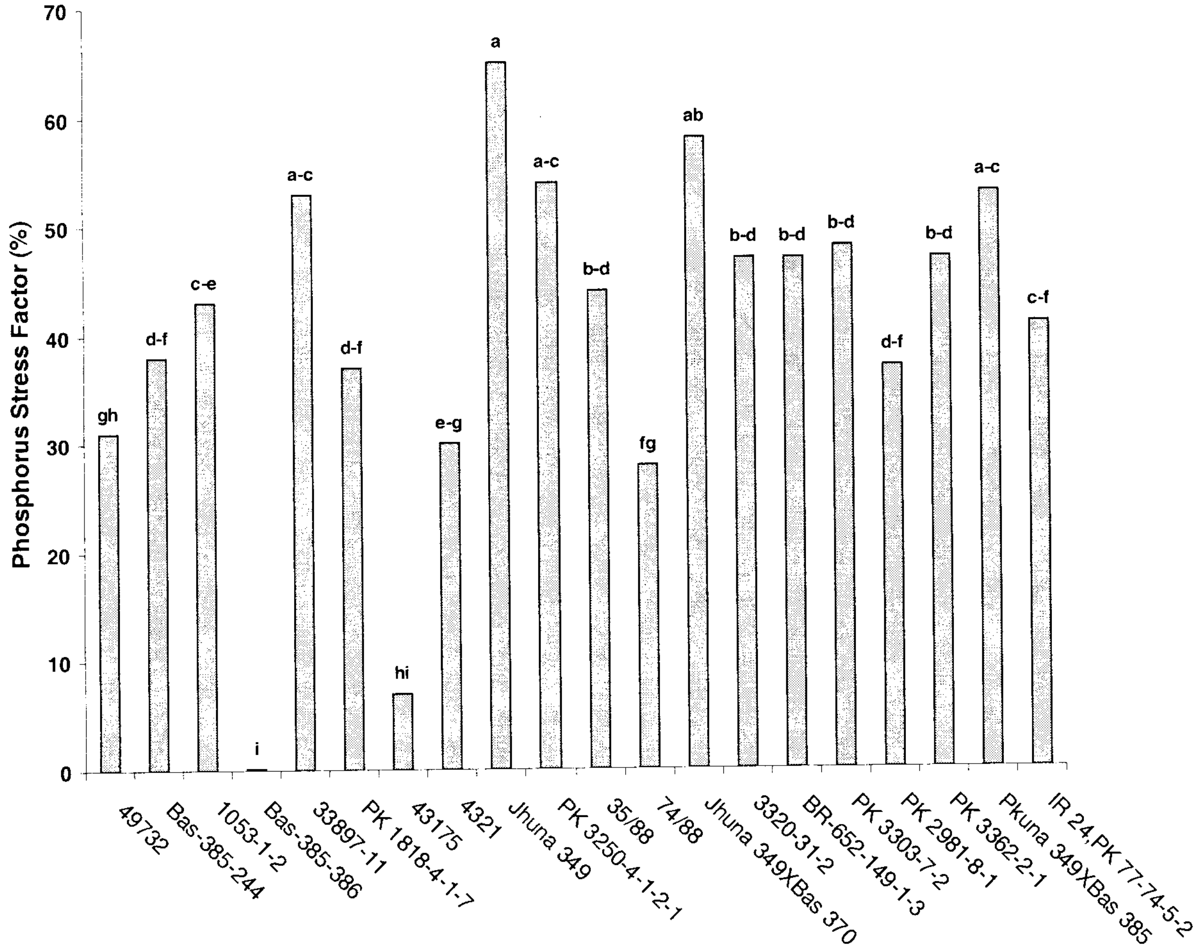

Fig.1. Percent reduction in SDM production in various rice cultivars due to P deficiency in root medium

claimed as efficient and most responsive to P since they produced increased SDM as the P supply in the growth medium was increased. Five cultivars (BR 652-149-1-3; 43175; Bas 385-244; 35/88 and 49732) are grouped as NENR, as they produced minimum biomass at both P levels. By comparing different morphological and physiological parameters of ER, NER, ENR and NENR cultivars, it is clear that specific P utilization rate of these cultivars is the main physiological parameter responsible for their efficiency in producing maximum biomass even at low level of P supply in the growth medium. These parameters are variable among cultivars even within each group, however, efficient cultivars had maximum SUR, P uptake and biomass production at deficient level of P supply.

CONCLUSION

Cultivars differed significantly for biomass production, root: shoot ratio and relative growth rates of shoot and root at both levels of P supply. Positive and significant correlation between SDM, RDM and TDM with P content, SUR, PTR and in PUI indicates that cultivars efficient in P uptake and transport rate (PK 3362-2-1; IR 24 PK 77-74-5-2; Jhuna 349; 1053-1-2) accumulated maximum biomass at deficient level of P supply. Identification of mechanisms related to increased absorption, translocation and utilization of P under P deficiency in responsive as well as efficient rice cultivars can be exploited to produce more P efficient cultivars.

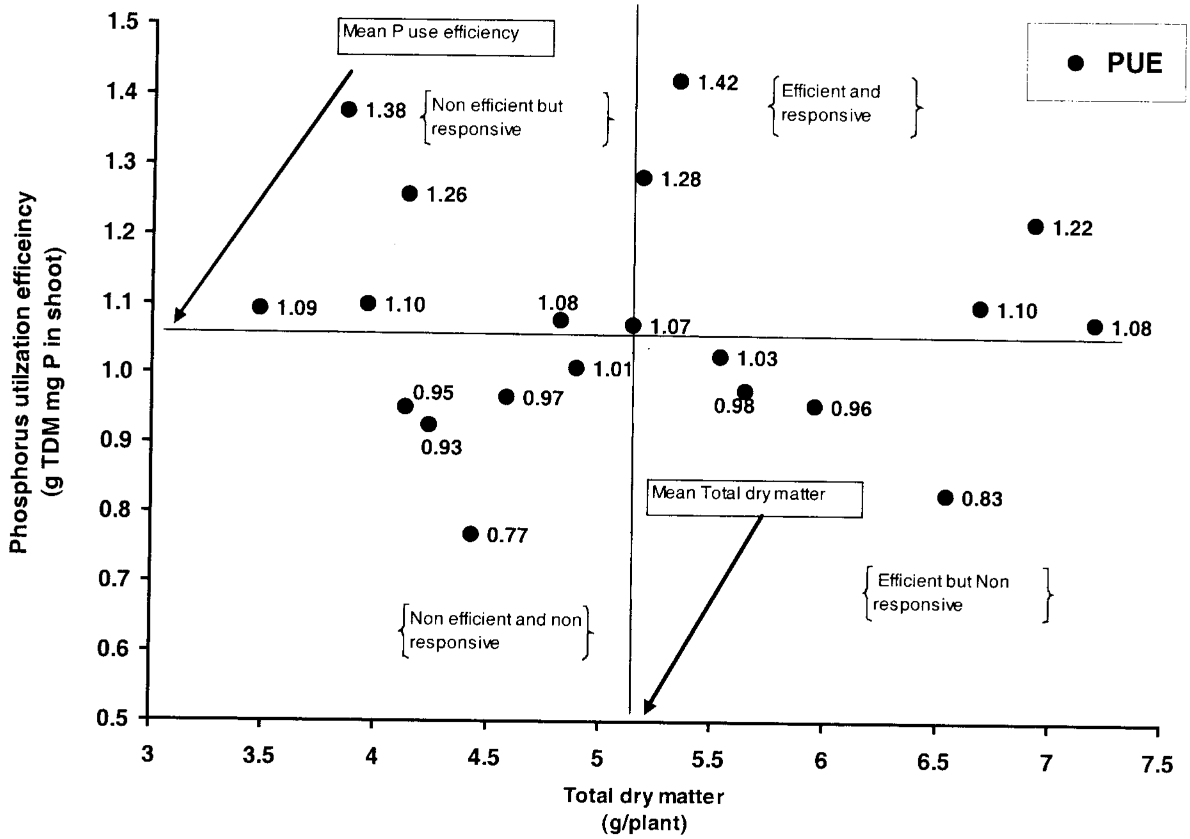

Fig.2. Catagorization of rice genotypes for their efficiency to P utilization

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