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Differences in Rice Cultivars for Growth and Phosphorus Acquisition from Rock Phosphate and Mono-ammonium Phosphate Sources

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ABSTRACT

Exploitation of genetic variations among crop species and genotypes for increased phosphorus (P) efficiency can sustain crop yields in soils low in available P. Five rice cultivars (viz. Basmati-385, Basmati-370, Super Basmati, Shaheen Basmati & NIAB-IR9) were evaluated for their growth response and P uptake from phosphate rock (PR) and mono-ammonium phosphate (MAP) in hydroponics. Shoot and root dry matter production, P concentration differed significantly ($p<0.01$) among cultivars grown either with PR and MAP. However, plants grown with MAP accumulated higher biomass and P contents than grown with PR. Phosphorus contents in plants grown with PR ranged between 2.20 to 5.14 mg per plant and it ranged between 19.51 and 34.82 mg per plant grown with MAP. Phosphorus utilization efficiency was maximum in NIAB-IR9, Basmati-370 and Basmati-385 when grown with PR, while in plants grown with MAP, Super Basmati, Basmati-385 and NIAB-IR9 exhibited maximum P use efficiency. Cultivars Basmati-385 and Basmati-370 produced higher biomass as well as P uptake. Further studies on P efficiency traits of these cultivars such as root morphological and physiological processes may improve our knowledge on P use efficiency in rice.

Key Words: Phosphorus efficiency; Acquisition; Phosphorus utilization; Root morphology

INTRODUCTION

Phosphorus (P) deficiency is common in agricultural soils mainly because of its precipitation with Ca and its adsorption on $CaCO_3$ in calcareous soils with high pH (Rahmatullah *et al.*, 1994) and its precipitation and adsorption with Fe and Al oxides in soils with low pH (Vance *et al.*, 2003). More than 80% soils in Pakistan are also deficient in available P (contain < 10 mg kg^{-1} Olsen-P; Memon, 2005). The P balance of Pakistani soils is negative (5-10 kg ha^{-1}) (Ahmad & Rashid, 2003). High pH and calcareousness is the major reason for low P availability in Pakistani soils as a major portion of total P exists as calcium phosphates of varying solubilities (Rahmatullah *et al.*, 1994). Application of phosphatic fertilizers is the common strategy to cope its deficiency, this option is not very much feasible because of low use efficiency of applied P, huge rise in its prices, environmental concerns and fear of depletion of non-renewable rock P reserves mined for production of P fertilizers (Vance *et al.*, 2003).

Raw phosphate rock contains almost no soluble P and plants generally can not uptake insoluble P. A number of plants have adopted strategies to solublize P in rooting medium. Nonetheless, cultivars differ in one or more strategies; hence show differential P acquisition from sparingly soluble or insoluble P sources (Gill *et al.*, 2002; Kosar *et al.*, 2002; Gahoonia & Nielsen, 2004; Aziz *et al.*, 2006; Aziz *et al.*, 2010). Exploitation of these genetic differences in field crops can greatly improve the fertilizer use efficiency and sustain agricultural productivity.

As rice is one of the major cash and cereal crops in Pakistan, its P acquisition ability and utilization must be explored. It was hypothesized that significant differences for P acquisition and utilization exist in rice cultivars, which may be used in future breeding ventures. This study was conducted to find out the differences in rice cultivars for P acquisition and utilization.

MATERIALS AND METHODS

This hydroponics study was conducted in a glass-roof wire house with no control on temperature and relative humidity. Seeds of five rice cultivars (Basmati-385, Basmati-370, Super Basmati, Shaheen Basmati & NIAB-

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IR9) were collected from Soil Salinity Research Institute (SSRI), Pindi Bhattian, Hafizabad. The seeds were geminated in pre-washed riverbed sand in polyethylene lined iron trays and irrigated with distilled water. One week after germination, uniform sized seedlings of each cultivar were transplanted in plastic pots containing 2 L of nutrient solution. Each pot was supplied with half strength modified Johnson's nutrient solution (Johnson *et al.*, 1957). Two P sources i.e., phosphate rock (PR) and mono-ammonium phosphate (MAP) were used in the study. Powdered rock phosphate was added @ 2 g L^{-1} in respective pots. Completely randomized design (CRD) was followed with three replicates. Hydrogen ion activity (pH) of the pots was monitored and adjusted at 6.0±0.5 in MAP treatment only, while it was not adjusted in PR treatment.

Harvesting was done after four weeks of transplanting and plants washed thoroughly with distilled water, blot dried using filter paper sheets and cut into roots and shoots with iron scissor. The samples were dried at 70°C in a forced air driven oven for 48 h and dry matter yield was recorded. Relative biomass production by rice cultivars grown with PR compared to MAP was calculated by using following formula.

$$\text{Relative dry matter production (\%)} = \frac{\text{DW in PR treatment}}{\text{DW in MAP treatment}} \times 100$$

Where, DW is the dry matter of shoot or root.

Dried samples of shoots and roots were ground in a grinding mill (MF 10 IKA, Werke, Germany) using 1 mm sieve. A small part of ground plant sample (0.5 g) was digested at 150°C in diacid mixture (nitric acid & perchloric acid) following Miller (1998). The digested material was analyzed for P concentration by spectrophotometer (Shimadzu, Japan) at wavelength 410 nm by the vanamolybdate yellow color method (Chapman, 1961). Phosphorus utilization efficiency was calculated by dividing the dry matter with P concentration (Siddiqui & Glass, 1981). The data was statistically analyzed using variance analysis technique.

RESULTS

Biomass production: Cultivars varied significantly for shoot dry matter (SDM) and root dry matter (RDM) grown either with PR or MAP. Shoot dry matter of rice cultivars was significantly ($p<0.01$) higher in MAP treatment than RP treatment (Table I).

Plants grown with PR accumulated significantly lower root dry matter (RDM) than plants receiving MAP. Root dry matter of rice cultivars ranged between 0.16-0.35 g $plant^{-1}$ when grown with PR. Maximum RDM of plants grown with PR was produced by Basmati-370 followed by Super Basmati and Shaheen Basmati. Root shoot ratio (RSR) of rice cultivars was significantly higher in plants grown with PR than those grown with MAP. Super Basmati exhibited the maximum RSR (0.23), when grown with MAP. In plants grown with PR, lowest RSR was observed in NIAB-IR9 (Table I).

Phosphorus concentration and use efficiency: Phosphorus concentration and use efficiency were significantly different among cultivars and there were significant interaction as well among P sources and cultivars (Table II). Shoot P concentration was higher in MAP than in PR treatment (Table II). Maximum shoot P concentration was observed in Basmati-385 and in Super Basmati when grown with PR and MAP, respectively.

Root P concentration was significantly lower in PR treatments than MAP (Table II). Root P concentration of rice cultivars ranged between 3.73 mg g^{-1} in Basmati-370 and 7.16 mg g^{-1} in basmati-385, grown with PR treatment. In plants grown with MAP, it ranged between 5.14 mg g^{-1} in Basmati-370 and 6.26 mg g^{-1} in Basmati-385.

There were significant ($p<0.01$) main and interactive effects of cultivars and P sources on shoot P contents. Phosphorus contents were significantly ($p<0.01$) lower (4 folds) in plants grown with PR than those grown with MAP. Phosphorus contents in shoots of rice cultivars grown with PR ranged from 1.13 mg per plant in Shaheen Basmati and 3.82 mg per plant in Basmati-385. In plants grown with MAP, shoot P contents ranged from 16.71 mg per plant in Shaheen Basmati to 30.60 mg per plant in Basmati-385. Root P contents were 6 fold higher in plants grown with MAP than those grown with PR in nutrient solution. Maximum root P contents (1.73 mg $plant^{-1}$) were accumulated by Super Basmati in PR treatment. In case of MAP, maximum root P contents were observed in Super Basmati (5.80 mg $plant^{-1}$).

Shoot P use efficiency was significantly ($p<0.01$) higher in plants grown with MAP than those grown with PR (Table III). Minimum shoot phosphorus use efficiency was observed in Shaheen Basmati when grown with PR, was

Table I: Shoot dry matter, root dry matter and root:shoot ratio of five rice cultivars (*Oryza sativa*) grown with mono-ammonium phosphate (MAP) and phosphate rock (PR). Values are mean of three replicates

Cultivars	Shoot dry matter (g per plant)		Root dry matter (g per plant)		Root:shoot ratio	
	PR	MAP	PR	MAP	PR	MAP
NIAB-IR9	0.46c	3.22ab	0.16e	0.71b	0.35b	0.22bc
BS-385	0.55c	3.88a	0.18e	0.67bc	0.35b	0.18bc
BS-370	0.36c	2.89b	0.35d	0.54cd	1.01a	0.19bc
S- BS	0.29cd	3.94a	0.25de	0.9a	0.85a	0.23bc
SH-BS	0.24cd	2.56b	0.23de	0.47d	0.97a	0.19bc
LSD	0.70		0.15		0.34	

Table II: Phosphorus concentration in shoots and roots of five rice cultivars (*Oryza sativa*) grown with mono-ammonium phosphate (MAP) and phosphate rock (PR). Values are mean of three replicates

Cultivars	Shoot P Concentration (mg P g^{-1})		Root P Concentration (mg P g^{-1})	
	PR	MAP	PR	MAP
NIAB-IR9	4.08d	6.37a	4.46bc	6.19ab
BS-385	6.92a	6.45a	7.16a	6.26ab
BS-370	3.44de	5.39b	3.73c	5.14b
S- BS	4.90c	6.52a	7.05a	6.41ab
SH-BS	4.75cd	5.90b	4.66bc	5.88a
LSD	0.86		1.37	

Table III: Phosphorus utilization efficiencies of five rice cultivars (*Oryza sativa*) grown with mono-ammonium phosphate (MAP) and phosphate rock (PR). Values are mean of three replicates.

Cultivars	Shoot PUE (g SDM mg^{-1} P)		Root PUE (g SDM mg^{-1} P)	
	PR	MAP	PR	MAP
NIAB-IR9	0.113c	0.474b	0.037de	0.114b
BS-385	0.080c	0.492b	0.026e	0.108bc
BS-370	0.104c	0.445b	0.094c	0.105bc
S- BS	0.060cd	0.664a	0.035de	0.141a
SH-BS	0.050cd	0.392bc	0.049d	0.080c
LSD	0.14		0.017	

followed by Super basmati, Basmati-385, Basmati-370 and NIAB-IR9 in ascending order. In case of MAP, the minimum shoot phosphorus use efficiency was observed in Shaheen Basmati, followed by Basmati-370, NIAB-IR9, Basmati-385 and Super Basmati.

Root P use efficiency was significantly ($p<0.01$) higher in MAP treatment than in PR (Table III). Phosphorus use efficiency was significantly more in Basmati-370, Shaheen Basmati and NIAB-IR9 than other cultivars in PR treatment. In plants grown with MAP, Super Basmati and NIAB-IR9 produced more biomass per unit P absorbed.

DISCUSSION

Ever-escalating prices of P fertilizers in the world in addition to increased environmental concerns of P application (Vance *et al*., 2003) have diverted the attention of scientists towards environmental friendly solutions such as genetic exploitation for P efficiency. Further tailoring of plants is more feasible than to tailor soil to fix the problem.

Significant reduction in growth and P uptake in plants grown with PR clearly indicated its low P solubility; however variations in growth indicated useful differences among rice cultivars for P acquisition from PR. These variations and interactive effects of P and cultivars should be used for producing more P efficient cultivars through recombinant breeding (Kang, 1998).

Under edaphic stresses, particularly facing nutrient deficiency, roots have to explore more soil volume; hence plants allocate more photosynthates towards ground than to shoots (Lynch, 1995; Kosar *et al.*, 2002; Aziz *et al.*, 2006). This judicious allocation altered root: shoot ratio in the present study. It was much higher in plants grown with PR than in MAP. Cultivars with high RSR would be promising to utilize more P than cultivars with low RSR (Aziz *et al.*, 2006).

Plants differ in their ability to uptake and utilize P from soil (Aziz *et al.*, 2006). Differences among cultivars for shoot and root P concentration clearly indicated the variations in uptake efficiency either from PR or MAP. Furthermore, differences within treatment suggested the significant variations among cultivars for utilization (Siddiqui & Glass, 1981; Aziz *et al.*, 2005). Cultivars with low P in tissues but with more biomass producer is needed for areas with low total or soluble P, whereas cultivars with more P contents and biomass are needed to be grown in areas, where application of P is not a problem.

Significant differences were also observed in rice cultivars for P utilization efficiency. Basmati-385 and Basmati-370 exhibited maximum P use efficiency when grown with PR. Nonetheless these cultivars were also efficient in biomass production.

CONCLUSION

Significant genetic variation was observed amongst rice cultivars for P efficiency. Cultivars Basmati-385 and Basmati-370 were at the top in terms of dry matter production and P uptake. However, results of this study warrants further research on morphological and physiological basis of these responsible for these differential responses.

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