Evaluation of Rice Genotypes for Phosphorus use Efficiency under Soil Mineral Stress Conditions

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Abstract

In order to identify the superior rice genotypes with higher P use efficiency, and also those tolerant to low soil P status, twenty eight pre-release promising rice varieties and hybrids were evaluated for their grain yield, and response to graded levels of applied phosphorus in a low soil-P fertility status calcareous vertisol (Olsen P: 2.04 ppm P) located, during *kharif* seasons of 2004 and 2005 at DRR farm, Rajendranagar, Hyderabad.

Among rice cultures, four distinct patterns in grain yield response were observed with eight rice cultures at 0 P-level , six rice cultures at medium P-fertility level (20-30 kg P_2O_5 ha^{-1}) were exhibiting higher grain yield response; while five recorded higher grain yields and yield response only at higher P-levels of 50 – 60 kg P_2O_5 ha^{-1} (65 – 93 kg grain/kg P_2O_5) compared to others (16 – 66 kg grain kg^{-1} P_2O_5). The other cultures IET 17190, Sumati and Rajavadlu did not show any grain yield response either at 0 – 10 or 50 – 60 kg P_2O_5 ha^{-1}; indicating the existence of genetic variability for P-use efficiency trait, which in conjunction with unraveling of physiological mechanisms underlying the observed genetic variation can be utilized for breeding elite rice culture with superior grain yield stability (either by conventional or by molecular breeding techniques) under soil minimal nutrient availability and / or nutrient stress conditions, with minimal dependence on chemical fertilizer inputs.

Key words : Low soil-P fertility status, phosphorus-use efficiency, rice genotypes, molecular breeding

Enhancement and sustainability of crop production in different rice growing system have become issues of national importance to meet the food and calorie energy requirements of Indian population.

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Although, this had been achieved during past four decades by adopting appropriate crop production practices, like adoption of suitable semi-dwarf HYVs and other agro-inputs, the present scenario indicates that during last six years, there had been a declining trend in rice grain yields mainly due to wide spread soil health problems, macro and micro-nutrient deficiencies, biotic and abiotic stresses. Among Indian rice growing soils, among major nutrients the Phosphorus (P) deficiency is widespread and it has become the most limiting nutrient next to nitrogen (N). Additionally, the farmers are not applying adequate quality of P fertilizer, in intensively rice cropped areas, and also in rice based cropping systems, mainly due to economic reasons, resulting in serious imbalance not only in soil fertility status, but also causing an erosion of soil organic base with resultant degradation of soil physical properties.

While application of mineral fertilizers at optimum dosages in conjunction with blend of organics and inorganic amendments may bring about an amelioration of the over- exploited soil fertility system; evolving superior rice cultivars which can utilize the soil nutrients present at sub-optimal levels, understanding of molecular basis of P nutrition and concerted efforts towards genetic manipulation of nutrient acquisition mechanism from soil nutrient pool have been elucidated as prime research priorities for long term sustainability of rice production.

Based on above research perspectives, in order to identify superior rice genotypes with higher P-use efficiency, and also those tolerant to low soil-P status., various pre-release mini-kit rice varieties and rice hybrids have been evaluated for their grain yield, response to graded levels of applied phosphorus, in a low soil-P fertility status calcareous vertisol located at DRR farm, Rajendranagar, Hyderabad.

Materials and Methods

In order to identify higher P-use efficient rice genotypes, thirteen high yielding varieties and three rice hybrids during *kharif,* 2004 *viz*. PRH-122, HRI-126, MPH-5401, Dhanarasi, Nidhi, IET 14554, IET 15358, IET 15420, IET 17020, IET 17278, IET 17430, IET 17467, IET 17475, IET 17476, IET 17544; Suraksha and twelve rice cultures during *kharif* 2005 ***viz***. Pant Sankar Dhan-1, PHB-71, PA6444, PA6201, IET9691, Sagar Samba, IET 11768, IET 13652, IET 17190, Early Samba, Sumati and Rajavadlu were evaluated at graded levels of P from 0 – 60 kg P_2O_5 ha^{-1} ie 0, 10, 20, 30 40, 40, 60 kg P_2O_5 ha^{-1} , for their grainyield response to applied P, in a calcareous vertisol of low soil phosphorus fertility status. The soil type of the experimental site is a calcareous vertisol with pH 7.94, available nitrogen of 214 kg/ha, available phosphorus of 2.04 ppm P, available potassium of 624 kg K_2O ha^{-1} and organic carbon of 0.61%.

After raising the nursery with recommended package of practices, in the main field 30-day old seedlings were planted with a spacing of 20x10 cm, in a split-plot design with P-levels as main plot and varieties as sub-plot treatments. At the time of planting, during last harrowing 40 kg Nitrogen, and 40 kg K_2O ha^{-1} were applied; while only nitrogen @ 40 kg N ha^{-1} was applied each time, at tillering and panicle initiation stages. After planting, the plots were kept saturated for first 6 days after transplanting and the field was flooded with 2-3 cm depth of water after 6 th day. The water level was gradually raised to 5-10cm and maintained till crop maturity.

Results and Discussion

The grain yield data indicated that during both the seasons, the treatment differences due to varieties, P-levels and their interaction effects were found to be significant. During *kharif* 2004, among varieties IET 14554 recorded higher grain yield even at low soil P level (*i.e.*, at 0 kg P_2O_5 ha^{-1}) of 3.63 t ha^{-1}, followed by PRH-122, Dhanarasi, IET 15358, IET 17467 and IET 17475 which recorded grain yields of 3.05 – 3.26 t ha^{-1}. However, at higher P -levels of 30 – 40 and 50 – 60 kg P_2O_5 ha^{-1}, PRH-122 was found to be superior, recording higher grain yields of 5.75 – 6.63 and 6.89 – 7.30 t ha^{-1}, respectively; compared to IET 14554 (4.95 – 5.65 and 6.23 – 6.80 t ha^{-1}, respectively). (Tables1-2). Among other cultures, IET 15358, IET 17467 and IET 17475 although exhibited low-P tolerance and higher yields at low-P levels of 10 and 20 kg P_2O_5 ha^{-1} (3.35 – 4.27 t ha^{-1}); at higher P-levels of 50 – 60 kg P_2O_5 ha^{-1}, they recorded low grain yields (5.54 – 5.85 t ha^{-1}); while Dhanarasi which exhibited higher yields at low-P, also recorded marginally higher yields at 60 kg P_2O_5 ha^{-1} (6.33 t ha^{-1}) over above three cultures but lower than PHR-122 and IET 14554.

The rice hybrids HRI-126 and MPH-5401, although were found to be not tolerant at 0 P kg P_2O_5 ha^{-1} level (2.46 –2.64 t ha^{-1}), they exhibited superior grain yields of 6.08 – 6.50 t ha^{-1} at 50 – 60 kg P_2O_5 ha^{-1} levels, indicating that they need higher initial-P to achieve similar grain yield as that of PRH-122 or IET 14544. The other cultures IET 17020, IET17278 and Nidhi were found to be neither low-P tolerant nor P-responsive at higher-P levels (1.18-4.66 t ha^{-1}).

During *kharif* 2005, IET 9691 and PA6201 exhibited higher grain yields of 1.58 – 3.15 t ha^{-1} at 0 – 10 kg P_2O_5 ha^{-1} of applied P; followed by PHB-71, PA6444 and Sagar Samba (1.04 – 1.11 and 2.00 – 2.88 t ha^{-1}). However, at higher P-levels, PHB-71, PA6201 and PA6444 were found to be superior and recorded highest grain yields of 4.78 – 5.52 and 5.97 – 6.66 t ha^{-1} at 50 – 60 P_2O_5 ha^{-1}; while IET 9691 recorded lower grain yields of 4.59 – 5.15 t ha^{-1}. (Tables 3-4). Sagar Samba, although recorded higher grain yields at 0 – 10 kg P_2O_5 ha^{-1} and 20 – 30 kg P_2O_5 ha^{-1} (1.11 – 2.88 and 3.24 – 3.36 t ha^{-1}) and higher yield response (107 – 178 and 61 – 75 kg grain kg^{-1} P_2O_5) at higher P levels, it recorded only marginal grain yields of 3.56 – 3.83 t ha^{-1} and response of 45 – 49 kg grain kg^{-1} P_2O_5. Similar marginal grain yield response was observed with Early Samba at 0 – 10 and 50 – 60 kg P_2O_5 ha^{-1} (1.30 – 1.65 and 2.69 – 3.35 t ha^{-1}). IET 13652 and IET 11768, although did not exhibit any low-P tolerance at lower P levels of 0 – 10 kg P_2O_5 (0.36 – 1.85 t ha^{-1}), they exhibited higher yield potential than the second group Sagar Samba and Early Samba at 60 kg P_2O_5 ha^{-1} (4.73 – 4.94 t ha^{-1}) and grain yield response of 65 – 66 kg grain kg^{-1} P_2O_5. The other cultures IET 17190, Sumati and Rajavadlu did not show any grain yield response either at 0 – 10 or 50 – 60 kg P_2O_5 ha^{-1} (0.30 – 0.69 and 1.53 – 3.24 t ha^{-1}).

In India , phosphorus deficiency is wide-spread in nearly 85 per cent of the soils and in-sufficient plant-available soil phosphorus can be a major constraint for rice production. While in highly acidic, P-fixing soils upland rice growing soils, this is a common problem, under lowland conditions also, P deficiency is becoming the main factor limiting performance of modern rice varieties under intensive rice production (De Datta *et al*. 1990). This is due to lack of locally available P-sources and the high cost of water soluble P-fertilizers and because of these reasons, resource-poor rice farmers are not applying adequate quantities of P. Additionally, some rice soils can quickly fix up to 90% of the added P fertilizer into less soluble forms (Dobermann *et al*. 1998). Therefore, an attractive, cost-effective and alternative strategy is to develop rice cultivars capable of extracting higher proportion of native as well as applied P.

In the present investigation, four distinct patterns in grain yield response was observed with eight rice cultures *viz*. IET 14554, PRH-122, IET 15358, IET17467, IET17473, IET15358, IET17476 and IET17475 recording significant low soil-P response and higher grain yields at 0-10 kg P_2O_5 /ha level ; six rice cultures *viz*. IET11768, IET17430, IET17544, IET 15420, Pant Sankar Dhan-1 and Sagar Samba exhibiting higher grain yields at medium P- fertility level of 20-40 kg P_2O_5 ha^{-1}; while five *viz*. PHB -71, PA6444, PA6201, HRI-126 and MPH 5401 recorded higher grain yields and yield response only at higher P-levels of 50 – 60 kg P_2O_5 ha^{-1} (65 – 93 kg grain kg^{-1} P_2O_5) compared to others (16 – 66 kg grain kg^{-1} P_2O_5).The other cultures IET 17190,IET 17020, IET17278, Sumati and Rajavadlu did not show any grain yield response either at 0 – 10 or 50 – 60 kg P_2O_5 ha^{-1}. Similar genetic variability among lowland and upland rice cultivars in their ability to exploit soil and fertilizer P were reported by (Wissuwa and Ae 2001b) and (Fageria *et al*. 1988); and rice varietal differences to produce higher grain yields under sub-optimal phosphorus conditions by Koyama *et al* (1973) and Ponnamperuma (1976).

Earlier studies on low P tolerance mechanisms, indicate that as P does not move freely into the rhizosphere, (in high P-fixing soil, as soil mineral constituents easily bind applied P), plants with better P utilization-ability may acquire P by expanding their root system, thereby exploring a greater soil volume (Loneragan, 1978). Low P tolerant plants may acquire hardly soluble P by excreting organic compounds capable of releasing soil-bound P and resultant P solubilization due to organic-anion excretion may be responsible for the bulk of P uptake by rice from a P-deficient soil (Kirk *et al*., 1999); while higher root metabolic activity and longevity of the root systems had been reported to be responsible, for better P utilization of two rice cultures, compared to their susceptible counterpart (Krishnamurthy *et al*., 2004). Since genetic variation in tolerance to P-deficiency could effectively be exploited for rice improvement; it is postulated that efforts should be intensified to screen available varieties as well as traditional land races, and identify the morphological and physiological mechanisms underlying the low P-tolerance or sensitivity under field conditions.

Conclusions

Summerised over two seasons, the results indicated that genetic variability exists among rice cultures in utilization of applied P and grain yield responses. Assuming that a minimum level of soil-P availability could be maintained in the rice fields by adapting suitable agronomic practices, this trait can be utilized for breeding elite rice cultures with superior grain yield stability and sustainability, under low available soil-P and high P-fixing soil conditions. Adaptability of certain varieties like IET 14554, PRH-122, IET 15358, IET17467, IET17473, IET15358, IET17476, IET17475, IET 9691 and PA 6201, for specific mineral stresses in the soil is an added quality and mere substitution of the variety itself is going to be a paying proposition under marginal soil fertility farming conditions, with minimal dependence on chemical fertilizer inputs.

Additionally, unraveling of bio-chemical and physiological mechanisms underlying the observed genetic variation could lead to further advances in identifying genes for tolerance to P deficiency, which may then be manipulated to attain levels of tolerance that are presently not achievable. As tolerance to P-deficiency is quantitatively inherited with both additive and dominant effects, progress through conventional breeding approaches may be slow; and more rapid progress in this regard can be achieved by molecular breeding. Studying of the phosphate deficit-inducible promoters; and in particular, the identification of unique regulatory elements that can be used for engineering phosphorous uptake or other traits, could provide a significant benefit, in molecular breeding program, in evolving superior rice cultivars with wider adaptation to abiotic stresses under different soil and agro-climatic conditions.

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Table 1: Effect of P levels on Grain yield (t ha^{-1}) of rice genotypes, *kharif* 2004.

S. No.	Variety	P –Levels (Kg P_2O_5 /ha.)							
		0	**10**	**20**	**30**	**40**	**50**	**60**	Mean
1	PRH122	3.27	4.05	5.15	5.75	6.63	6.89	7.30	**5.58**
2	HRI126	2.46	3.52	3.95	4.56	5.03	6.08	6.51	**4.59**
3	MPH-5401	2.64	3.70	4.53	5.18	5.59	6.08	6.56	**4.90**
4	Dhanarasi	3.11	3.39	4.24	5.02	5.66	6.02	6.34	**4.83**
5	Nidhi	1.80	3.49	3.03	3.26	3.87	4.17	4.39	**3.43**
6	IET 14554	3.63	3.98	4.47	4.91	5.65	6.24	6.80	**5.10**
7	IET 15358	3.20	3.79	4.27	4.67	5.38	5.86	5.74	**4.70**
8	IET 15420	1.82	2.27	2.93	3.50	4.77	5.31	5.61	**3.74**
9	IET 17020	1.18	1.73	2.60	3.05	3.55	3.93	4.69	**2.96**
10	IET 17278	1.71	2.42	3.28	3.57	3.69	4.15	4.61	**3.35**
11	IET 17430	0.94	2.39	3.30	3.74	4.30	4.98	5.48	**3.59**
12	IET 17467	3.09	3.57	4.15	4.78	5.12	5.58	5.86	**4.59**
13	IET 17475	3.05	3.35	3.58	4.11	4.78	5.54	5.84	**4.32**
14	IET 17476	2.04	3.31	3.64	4.11	4.70	5.28	5.71	**4.11**
15	IET 17544	2.28	3.45	3.73	4.2	5.22	5.58	5.86	**4.33**
16	Suraksha	1.65	2.56	3.99	4.24	4.67	4.92	5.48	**3.93**
	Mean	**2.37**	**3.19**	**3.80**	**4.29**	**4.91**	**5.41**	**5.80**	**4.25**

C.D. (0.05): P- levels: 0.07 P at same V: 0.26 **C. V. (%)**: P- levels: 3.16
Varieties: 0.12 V at same P: 0.27 Varieties: 3.74

Table 2: Grain yield response of rice genotypes (kg grain/kg P_2O_5) to P application (*kharif* , 2004)

Varieties		P –Levels (Kg P_2O_5 ha^{-1} .)					
		10	**20**	**30**	**40**	**50**	**60**
1	PRH 122	78.9	94.4	82.7	84.1	72.5	67.2
2	HRI 126	105.9	74.7	70.1	64.3	72.4	67.5
3	MPH 5401	106.1	94.3	84.5	73.6	68.7	65.2
4	Dhanarasi	28.9	56.8	64.0	63.8	58.3	53.8
5	Nidhi	168.2	61.3	48.7	51.6	47.2	43.1
6	IET 14554	35.1	42.5	42.7	50.7	52.2	53.0
7	IET 15358	59.0	53.3	48.8	54.4	53.2	42.4
8	IET 15420	45.8	55.5	56.1	73.8	69.9	63.3
9	IET 17020	54.5	71./1	62.3	59.3	54.9	58.0
10	IET 17278	70.9	78.9	62.1	49.7	48.8	48.3
11	IET 17430	145.6	118.1	93.4	84.1	81.0	46.1
12	IET17467	48.1	53.2	56.3	50.8	49.7	46.1
13	IET 17475	29.7	26.4	35.5	43.3	49.8	46.6
14	IET 17476	126.5	79.7	68.9	66.4	64.7	61.2
15	IET 17544	117.1	72.8	64.1	73.5	66.1	59.6
16	Suraksha	90.4	116.6	86.3	75.4	65.4	63.7

Table 3: Effect of P-levels on grain yield of rice genotypes (t ha^{-1}), *kharif* 2005.

Varieties		P –Levels (t P_2O_5 ha^{-1}.)							
		0	10	20	30	40	50	60	Mean
1	Pant Sankar Dhan-1	0.37	1.33	2.25	3.26	3.28	3.42	4.09	2.57
2	PHB-71	1.04	2.69	3.24	3.69	4.22	4.79	5.97	3.66
3	PA6444	1.05	2.00	3.29	4.38	4.76	5.29	6.60	3.91
4	PA6201	1.58	2.90	3.94	4.69	5.28	5.52	5.99	4.27
5	IET 9691	1.83	3.15	3.37	3.44	4.29	4.59	5.15	3.69
6	Sagar Samba	1.11	2.88	3.24	3.37	3.55	3.56	3.83	3.08
7	IET 11768	0.82	1.85	2.14	2.87	3.42	3.97	4.73	2.83
8	IET 13652	0.95	1.76	1.96	2.55	3.42	3.58	4.94	2.74
9	IET 17190	0.30	0.51	0.60	0.71	0.92	1.08	1.53	0.81
10	Early Samba	1.30	1.65	1.92	2.37	2.36	2.69	3.35	2.23
11	Sumati	0.56	1.22	1.33	1.90	2.39	2.44	2.91	1.82
12	Rajavadlu	0.69	1.83	2.10	2.63	3.04	3.26	3.24	2.40
	Mean	0.97	1.98	2.45	2.99	3.41	3.68	4.36	2.83

C.D. (0.05): P- levels: 0.20 P at same V: 0.54 **C.V.(%)** : P- levels :0.06
Varieties: 0.16 V at same P: 0.54 Varieties: 9.53

Table 4 : Grain yield response of rice genotypes to applied- P (Kg grain/Kg P_2O_5). *kharif*, 2005.

Varieties		**P –Levels (Kg P_2O_5 ha^{-1}.)**					
		10	**20**	**30**	**40**	**50**	**60**
1	Pant Sankar Dhan-1	96.5	94.1	96.5	72.8	61.1	62.0
2	PHB-71	164.6	110.1	88.4	79.5	74.9	82.2
3	PA6444	95.1	111.8	110.9	92.7	84.8	92.6
4	PA6201	132.0	118.1	103.5	92.4	78.8	73.4
5	IET 969	132.0	76.8	53.7	61.5	55.1	55.3
6	Sagar Samba	177.6	106.5	75.4	61.1	49.1	45.4
7	IET 11768	102.8	66.0	68.3	65.1	62.9	65.2
8	IET 13652	80.6	50.4	53.3	61.7	52.5	66.5
9	IET 17190	21.5	14.9	13.6	15.6	15.6	20.5
10	Early Samba	34.7	31.3	35.6	26.5	27.7	34.2
11	Sumati	66.6	38.9	44.7	45.8	37.8	39.2
12	Rajavadlu	113.2	70.5	64.4	58.8	51.3	42.4