Oryza Vol. 54 No. 1, 2017 (21-28)

Comparison of morpho-physiological traits and root architecture of tolerant and susceptible rice genotypes under both phosphorus and water stressed and normal condition

RK Panda[2], E Pandit[1], SK Dash[1], M Kar[2] and SK Pradhan[1*]

[1]ICAR-National Rice Research Institute, Cuttack-753006, Odisha, India

[2]Orissa University of Agriculture & Technology, Bhubaneswar-751003, Odisha, India

Corresponding author e-mail: pradhancrri@gmail.com

Received : 06 April 2017 Accepted : 12 May 2017 Published : 19 May 2017

ABSTRACT

A comparison study of root architecture and morpho-physiological traits were taken up using nine tolerant and three check germplasm lines. The experimental work was done under rain protected condition using an innovative approach. A significant differences was observed in the root and shoot length of Pup1 positive genotypes than Pup1 negative germplasm lines under both phosphorous supplemented and deficient soil conditions. A higher uptake of phosphorus was noticed in Pup1 positive plants of leaf phosphorus analysis under water stressed condition as compared to normal. The higher p-uptake genotypes showed higher tiller number and high plant dry weight. The Pup 1 negative genotypes showed low root width and low root density than the positive plants. The Pup1 positive plants showed higher root dry weight, root length and root density under both phosphorus and water stress condition.

Key words: *Phosphorus deficient soil, phosphorus supplement soil, phosphorus stress tolerant, root density, root volume, root weight*

Rice is grown in a wide range of environments, but more than 40% of global rice production is from rain-fed ecosystem with limited control on water which is often associated with drought, flood or other calamities. Moreover 60% of rain-fed soils are deficient in one or more nutrients (Haefele and Hijmans 2007). In these soils, phosphorus (P) is one of the most important macro nutrients that is limited in availability. There is no substitute for P in food production and it is considered as the most limiting mineral nutrient for plants across all arable land (Kochian 2012). Most of the P is tightly bound to the soil. It is present either as unavailable form or slowly available form, which is not immediately accessible by plants. However, plants have evolved many adaptations to low concentrations of available phosphate in the soil. The induction of high affinity phosphate transporters and the secretion of acid phosphatase and organic acids contribute to the mobilization of phosphate from organic and inorganic substrates and active uptake of phosphorus (P) from the rhizosphere (Gardner *et al*. 1983; Tadano and Sakai 1991; Mucchal *et al*. 1996; Mucchal and Raghothama 1999; Liu *et al*. 2001; Kai *et al*. 2002; Wasaki *et al*. 2003a). It is also clear that P is efficiently utilized once inside the plant tissue (Duff *et al*. 1989, 1991). P deficiency causes reduction of leaf expansion and the number of leaves (Marschner 1995). Phosphorus (P) is of unequivocal importance for the production of food crops. It is often referred as the "energizer" since it helps to store and transfer energy during photosynthesis. It is a vital component of ATP, the 'energy currency' of the cell. It forms the basic component of many organic molecules, nucleic acids and proteins (Lea and Miflin 2011). Only 1% of P is present as available form in the soil solution which is found in irrigated ecosystems, where rice is grown in water logged conditions. There

is a scarcity of P in most of the soils and hence soils are to be replenished with P fertilizers regularly. The major QTL for phosphorus uptake was mapped on the long arm of chromosome 12 and is referred as *Pup1*. *Pup1* region in the chromosome contain the transcription factor gene *OsPTF1* which confers tolerance to P deficiency (Yi *et al*. 2005). Moreover, the research experiments showed that the *Pup1* enables the plants to increase P uptake by 3- to 4-fold primarily because it conferred strong and high root growth rates despite of P deficiency in soils (Ismail *et al*. 2007). Root morphological and physiological studies indicated that the *Pup1* gene expresses in root tissue where it either leads to higher root growth per unit P (higher internal efficiency) or improves P uptake per unit root size (external efficiency) (Wissuwa 2003). Therefore, varieties with *Pup1* locus might contain the morphologically and physiologically favorable root structure for the efficient usage of P uptake. It was observed in experiments that rice with *Pup1* extract up to 3 times as much naturally occurring soil phosphorus, tripling the grain yield and dry weight (Fredenburg 2006). The *Pup1* region sequenced by Heuer *et al*. (2009) confirmed that 278-kbp sequence of Kasalath rice variety was significantly different from the syntenic regions in Nipponbare rice variety due to large insertions or deletions (INDELs) that is directly linked with P deficiency tolerance. It is reported that the impact of *Pup1* on enhancing yield in P-deficient soil under drought stress is significantly high (Bernier *et al*. 2009; Venuprasad *et al*. 2009). *Pup1* is present in 80-90% of the upland and lowland/irrigated varieties. Underlying *Pup1* is a single kinase gene, OsPupK46-2 which is located in the indel which is closely associated with P deficiency and is highly conserved in the drought tolerant accessions in the rice germplasm (Chin *et al*. 2010, 2011). This gene underlying the *Pup1* locus increases early root growth and P acquisition efficiency under low-P conditions in several different genetic backgrounds and is subsequently named Phosphorus-starvation tolerance 1 (PSTOL1), which encodes a serine/ threonine kinase of the LRK10L-2 subfamily (Gamuyao *et al*. 2012). The *PSTOL1* gene also plays a role in lignification of rice roots in response to drought and P-stress (Tyagi *et al*. 2012). They also hypothesized that two QTLs *Pup1* and *Yld12.1* might be pleiotropic and introgression of this region might help select simultaneous P deficiency tolerance as well as for yield under drought. According to Chin *et al*. (2011), *pup1* has been successfully introgressed into two irrigated rice varieties, namely IR64 and IR74 and three Indonesian upland varieties, namely Dodokan *et al*. (2012) have identified four genotypes containing *Pup1*, namely Sahbhagi dhan, Dagaddeshi, Pynthor and Paijong, adapted to North Eastern and Eastern part of India, as potential donors for rice breeding for P deficiency tolerance. This study was carried out to compare the root architecture of tolerant and susceptible rice genotypes under phosphorus deficient and water stressed situation with normal condition.

MATERIALS AND METHODS

Plant materials

Twelve rice genotypes comprising of 9 tolerant and three check genotypes as suggested by Pandit *et al.* 2016 were selected for the present study (Table 1). Seeds of these germplasm lines were collected from ICAR-National Rice Research Institute (NRRI), Cuttack.

Experimental site

An experiment was carried out in a raised brick structured tank at ICAR-National Rice Research Institute (NRRI), Cuttack (latitude 25.30N, longitude 85.15E) during dry season of 2015. The tank was made collapsceable type by providing low proportion of sand to cement (20:1) in the walls. The inside wall length was 18ft, inside breadth-6.5ft, 3ft height above ground and 1.5ft below ground with each tank was partitioned into two sub-tanks by a middle wall with size 18'x3"x3' (above ground). The tanks were filled with phosphorus deficient soil (around 660cft) collected from other lands having loamy sand with pH 4.21, organic carbon 0.573 %, having available nitrogen, phosphorous, exchangeable potassium of 150, 14.08 and 25.54 kg ha^{-1}, respectively. To estimate soil phosphate, Olsen *et al*. (1954) method was adopted. The soil height was maintained up to 3ft in each tank. The tank soil was leveled uniformly and irrigated. Six moisture meter probes were inserted in each tank to assess the moisture content of the tank. One/two seeds of individual genotypes were sown 2cm below the soil. The experiment was replicated twice with split plot design in four main plot (stress, no stress, with application of phosphorus and without application of phosphorus) and twelve genotypes in subplots. After germination, single

seedling was maintained. Both water stress and no stress (control) tanks were fertilized at the rate of 80, 40 and 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively. Phosphorus was not applied in one tank to study *Pup1* action. Nitrogen was applied on three occasions, *viz*., 1/3rd each at basal, maximum tillering and panicle initiation stages, while the P_2O_5 and K_2O were applied as basal application.

P uptake ability and assessment of phenotypic traits in phosphorus deficient and supplemented soil

For the soil experiment, the Pup1 positive and checks (12 rice genotypes) (Table 1) *viz*., Bowdel, Lalsankri, Karni, Dinoroda, N-22, Bamawypan, Tepiboro, Dular , Surjamukhi, and three check varities Kasalath, IR-64, and Kalinga-III, 1 plant from each variety were grown in a tank described above with natural light conditions for 45 days. Soil was kept aerobic, but well watered without draining at all times. Thereafter the stress was imposed in one tank and other kept as such for another 15days. Eight quantitative morpho-physiological characters were measured in each plant. Tiller number, leaf area, root length (cm), shoot length (cm), root density (mass per volume), root dry weight (g) and shoot dry weight (g) were measured. Root volume was measured by measuring the spilled content of water. P uptake in rice leaves was also quantified both in P deficient and P supplemented soil during the said period.

Statistical analysis

Physiological and biochemical data were analyzed following the split plot design as outlined by Gomez and Gomez 1984 and Panse and Sukhatme 1985.

RESULTS AND DISCUSSION

Morpho-physiological studies indicated that the *Pup1* gene express in root tissue where it either leads to higher root growth per unit P or improves P uptake per unit root size (Wissuwa *et al*. 2002). It is also reported that the impact of *Pup 1* and other QTLs on enhancing yield in P-deficient soil under drought stress is significantly high (Bernier *et al*. 2009; Venuprasad *et al*. 2009). Hence, genotypes with *Pup1* locus might have contained the morphologically and physiologically favourable root structure for the efficient usage of P uptake. Evaluation of phenotypes for relative tiller number (tiller number under P-deficiency relative to non-stress tiller number) has been used as an indirect estimate for P uptake (Ni *et al*. 1998). Employing a relative parameter allows for comparisons in stress response between a variety of diverse genotypes without confounding effects due to substantial differences in tillering ability. Without variation under optimum P supply, the relative tiller number entirely depends on the number of tillers produced under P deficiency.

Association between *Pup1* containing genotype, water stress and shoot/ root traits in soil experiment

Table 1. Twelve rice genotypes used for root architecture study under water and phosphorus stressed and normal conditions

Sl.No.	Genotype	Pup1K-20 240bp (Kasalath allele)/ 243bp (Nipponbare allele) 59^{0}C	Pup1-K42 918bp was obtained at 57^{0}C	Pup1-K46 523bp was obtained at 59^{0}C	Closely associated microsatellite marker RM28073 656bp was obtained at 57^{0}C	Closely associated microsatellite marker RM28102 168bp was obtained at 57^{0}C
1	Bowdel	+ve	+ve	+ve	+ve	+ve
2	Lalsankri	+ve	+ve	+ve	+ve	
3	Karni			+ve	+ve	+ve
4	Dinoroda		+ve		+ve	+ve
5	N-22		Non-specific	+ve	+ve	+ve
6	Bamawypan*		+ve	+ve	+ve	+ve
7	Tepiboro		+ve	+ve	+ve	+ve
8	Dular*		Non-specific	Non-specific	-ve	Not detected
9	Surjamukhi*		+ve	+ve	-ve	-ve
10	Kasalath	+ve	+ve	+ve	+ve	+ve
11	IR-64	-ve check	-ve check	-ve check	-ve check(600bp)	-ve check(155bp)
12	Kalinga-III	Not detected	Not detected			

* drought tolerant genotypes and have deeper rooting ability.

Table 2. Morpho-physiological effect of stress and no stress on rice plant in P-deficient and P-sufficient soil during vegetative stage of the crop (water stress imposed 45DAS)

Shoot dry weight (g)												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	42.05	61.85	59.7	59.34	19.04	22.95	29.35	31.84	23.35	99.04	89.67	91.2
S1	23	29.92	16.8	27.66	23.27	35.52	20.82	21.41	12.59	39.76	23.02	20
P0	23.76	26.29	35.9	28.04	20.43	24.8	31.33	12.74	12.41	38.01	45.04	46.5
P1	41.29	65.48	40.6	58.97	21.88	33.68	18.84	40.52	23.53	100.8	67.65	64.6
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	9.823	ns	22.2	S x P	13.89	ns	22.2	V× S/P	0.775	2.208		
P	9.823	ns	22.2	Varieties	0.548	1.561	0.506	S/P× V	97.05	435.8		
Root dry weight (g)												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	11.79	14.71	17.8	16.6	11.41	16.86	9.25	13.19	13.4	25.02	15.13	31.7
S1	11.94	4.09	2.57	12.23	9.62	16.11	9.86	17.43	4.94	11.9	8.11	5.19
P0	8.96	5.52	9.74	7.13	10.62	16.33	9.8	6.53	8.04	12.01	7.77	16.2
P1	14.76	13.29	10.6	21.7	10.42	16.63	9.32	24.09	10.31	24.91	15.47	20.7
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	2.69	ns	6.08	S x P	3.804	ns	6.08	V× S/P	1.221	3.479		
P	2.69	ns	6.08	Varieties	0.863	2.46	0.797	S/P× V	8.601	36.45		
Total biomass (g)												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	53.84	76.56	77.5	75.94	30.45	39.81	38.6	45.04	36.75	104.4	104.8	123
S1	34.94	34.01	19.4	52.63	32.9	51.63	30.68	38.84	17.53	51.66	31.13	25.2
P0	32.72	31.8	45.7	35.17	31.05	41.13	41.13	19.27	20.44	50.02	52.81	62.8
P1	56.05	78.77	51.2	93.4	32.29	50.31	28.15	64.61	33.84	106.1	83.12	85.3
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	11.67	ns	26.4	S x P	16.5	ns	26.37	V× S/P	0.82	2.336		
P	11.67	ns	26.4	Varieties	0.58	1.652	0.535	S/P× V	136.7	614.3		
% Nitrogen content												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	1.6	1.73	1.4	1.95	1.95	2.1	1.75	1.38	1.9	1.59	1.68	1.51
S1	1.99	2	2.02	1.82	1.53	2.3	1.82	2.08	1.77	1.73	1.64	1.93
P0	2.03	1.98	1.77	1.86	1.82	2.06	1.75	1.75	1.68	1.53	1.9	1.75
P1	1.56	1.75	1.65	1.9	1.66	2.34	1.82	1.71	1.99	1.79	1.42	1.68
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	0.04	0.171	0.09	S x P	0.05	ns	0.09	V× S/P	0.05	0.15		
P	0.04	ns	0.09	Varieties	0.04	0.1	0.03	S/P× V	0	0.01		
% Phosphorus content												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	0.24	0.25	0.33	0.21	0.21	0.23	0.28	0.2	0.3	0.18	0.19	0.25
S1	0.19	0.22	0.2	0.2	0.19	0.23	0.21	0.17	0.16	0.1	0.12	0.18
P0	0.23	0.21	0.3	0.19	0.21	0.25	0.24	0.18	0.23	0.15	0.14	0.29
P1	0.2	0.26	0.24	0.21	0.19	0.22	0.25	0.19	0.24	0.13	0.17	0.13
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	0.008	0.038	0.02	S x P	0.012	ns	0.019	V× S/P	0.004	0.012		
P	0.008	ns	0.02	Varieties	0.003	0.008	0.003	S/P× V	0	0		
% Potash content												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	1.6	1.36	1.28	1.27	1.39	1.35	1.23	1.27	1.52	1.29	1.18	1.54
S1	1.91	1.66	1.6	1.84	1.69	1.48	1.82	1.73	1.5	1.67	1.36	1.42
P0	1.95	1.49	1.38	1.79	1.64	1.36	1.72	1.66	1.79	1.53	1.38	1.51

Contd.....

Contd.....

P1	1.56	1.53	1.5	1.33	1.44	1.48	1.33	1.34	1.23	1.43	1.17	1.45
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	0.088	ns	0.2	S x P	0.124	ns	0.199	V× S/P	0.075	0.213		
P	0.088	ns	0.2	Varieties	0.053	0.15	0.049	S/P× V	0.013	0.049		
Tiller number per plant												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamaw-ypan	Tepiboro	Dular	Surja-mukhi	Kasalath	IR-64	Kalinga-III
S0	9	25.25	15.5	16	10	4.75	11.5	7	6.25	20	14	8.7
S1	8.5	25.75	11.75	17.5	22	21.75	19.25	14	12	15.5	12.5	12.7
P0	6.75	19.5	9.5	8.25	16.25	8.75	12.25	8.25	6.5	12.75	11.5	12
P1	10.75	31.5	17.75	25.25	15.75	17.75	18.5	12.75	11.75	22.75	15	14.5
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	3.028	ns	6.844	S x P	4.282	ns	6.844	V× S/P	3.536	10.22		
P	3.028	ns	6.844	Varieties	2.536	7.227	2.34	S/P× V	20.957	74.849		

* drought tolerant genotypes and have deeper rooting ability. S0- stress, S1-irrigated & P0-phosphorus not applied, P1-phosphorus applied

Table 3. Contribution of assimilates and inorganic ions towards development of plant parts

% root partitioning

	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamawypan	Tepiboro	Dular	Surjamukhi	Kasalath	IR-64	Kalinga-III
S0	36.02	17.83	22	42.54	39.08	37.96	24.33	49.67	46.77	27.42	16.52	27.8
S1	30.97	14.7	15.5	40.7	29.91	33.65	28.76	40.99	30.51	26.57	26.5	33.7
P0	37.28	18.29	15.6	45.74	33.99	35.76	25.87	46.13	37.04	23.83	17.77	30.6
P1	29.71	14.24	21.9	37.49	35	35.85	27.21	44.53	40.25	30.16	25.25	30.9
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	5.028	ns	11.4	S x P	7.11	ns	11.36	V× S/P	0.53	1.511		
P	5.028	ns	11.4	Varieties	0.375	1.068	0.346	S/P× V	25.54	114.5		
% shoot partitioning												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamawypan	Tepiboro	Dular	Surjamukhi	Kasalath	IR-64	Kalinga-III
S0	63.98	82.17	78	57.46	60.92	62.04	75.67	50.33	53.23	72.58	83.48	72.2
S1	69.03	85.3	84.6	59.3	70.34	66.35	71.24	59.01	69.49	73.43	61.64	66.4
P0	62.72	81.71	84.5	54.26	66.01	64.24	74.13	53.87	62.96	76.17	82.73	69.5
P1	70.29	85.76	78.1	62.51	65.25	64.15	72.79	55.47	59.75	69.84	62.39	69.1
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	5.569	ns	12.6	S x P	7.875	ns	12.59	V× S/P	0.498	1.419		
P	5.569	ns	12.6	Varieties	0.352	1.003	0.325	S/P× V	31.24	140.2		
Root density												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamawypan	Tepiboro	Dular	Surjamukhi	Kasalath	IR-64	Kalinga-III
S0	0.08	0.1	0.12	0.11	0.07	0.11	0.06	0.09	0.08	0.12	0.09	0.21
S1	0.07	0.03	0.02	0.15	0.06	0.1	0.06	0.1	0.03	0.08	0.05	0.03
P0	0.06	0.04	0.07	0.05	0.07	0.1	0.06	0.04	0.04	0.08	0.05	0.11
P1	0.09	0.09	0.07	0.22	0.07	0.1	0.06	0.15	0.07	0.12	0.09	0.13
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	0.02	ns	0.04	S x P	0.03	ns	0.04	V× S/P	0	0.01		
P	0.02	ns	0.04	Varieties	0	0.01	0	S/P× V	0	0		
Root length (cm)												
	Bowdel	Lalsankri	Karni	Dinoroda	N-22	Bamawypan	Tepiboro	Dular	Surjamukhi	Kasalath	IR-64	Kalinga-III
S0	48.75	48	57	55.88	58.75	57.25	46.25	50.55	81.5	70.3	69.88	55.6
S1	63.68	56.38	47.3	76.3	71.3	70.75	65.38	72.75	54.18	58.38	77.13	55.1
P0	51.18	51.5	49.3	67.75	63.55	64.25	62.38	58.25	75.55	51.05	71.13	52
P1	61.25	52.88	55	64.43	66.5	63.75	49.25	65.05	60.13	77.63	75.88	58.8
	Sem	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**		**Sem**	**CD(5%)**	**CV(%)**	
Stress	2.666	ns	6.03	S x P	3.771	ns	6.027	V within S/P		5.996	17.09	

Soil P level determined by Olsen *et al*. (1954) was found as 14.08kg ha^{-1} at the 4.21 pH level. Significant differences were observed in the root length between *Pup1* positive variety group and *Pup1* negative variety group in both phosphorous supplemented and deficient soil conditions (Table 2). Significant differences were not observed in the shoot length between the *Pup1* positive variety group and *Pup1* negative variety group under both phosphorous supplemented and deficient soil conditions. Out of the twelve rice genotypes used in this study, Karni showed the highest content of P in the plants of P deficient soil followed by Kasalath and Bowdel which were to a tune of 20%, 13.33% and 13.04%, respectively. Similarly, during water stress situation also a significant difference in P uptake was observed when the leaf P availability was measured. A similar result was reported by Sarkar *et al*. 2011. Among these twelve genotypes, five genotypes showed significantly higher P content in leaves both under P deficient and P sufficient soils were Karni, Bowdel, Dinoroda, Kasalath and Kalinga III. It has been found that genotypes with high P-uptake ability have significantly higher plant dry weight (93.4g $plant^{-1}$) than that of average 63.59g $plant^{-1}$. Similar trend was also observed in tiller number per plant as reported by (Ni *et al*. 1998) and in N and K uptake. Significant differences were observed in the root length and root density between the *Pup1* positive genotype group and *Pup1* negative rice genotype group under phosphorous supplemented and deficient soil conditions. The *Pup1* gene positive group has increased the dry weight of root by 16.01g under P supplemented condition and by 9.89g under P deficient soil condition. Under both condition although the shoot length was not significant, shoot dry weight was highly significant at *Pup1* gene positive variety group has increased the root density by about 50% when compared with null *Pup1* group (Table 3). However, the comparative studies among the genotypes revealed that Bowdel, Lalsankri and Karni had better root dry weight having 14.76g, 13.29g and 9.74g, respectively than the rest. When the root width and root volume traits were analysed, it was noted that all individual varieties in *Pup1* negative group, Kalinga III and IR64 had produced low root width and low root density comparatively to other 10 genotypes that contained *Pup1* in P deficient condition. Gupta and Guhey (2011) also reported similar type of finding. Gloria *et al*. (2002) reported that the water deficit in rice caused a larger reduction in leaf area than shoot dry matter, demonstrating the greater sensitivity of leaf enlargement to water stress than dry matter accumulation. As the main organ of plants that take up nutrients, roots play an important role in phosphorous acquisition from soils which was clearly revealed in dry matter partitioning of assimilates towards development of plant organs. In this study root and shoot related traits of *Pup1* positive varieties and *Pup1* negative varieties were analysed by pooling the respective data in order to confirm the general contribution from *Pup1* locus to root and shoot growth. Results revealed that *Pup1* positive genotypes integrate different root traits that contribute to the adaptation to low phosphorous availability and therefore more tolerance to phosphorous deficiency is appeared as compared to *Pup1* negative genotypes during water stress conditions also. Similar result was also reported by Kottearachchi *et al*. 2013.

The comparative study revealed that there is a significant difference between rice with *Pup1* positive genotypes and the rice with *Pup1* negative genotypes, in root width, root dry weight, root volume and shoot dry weight under phosphorus and water stressed condition as compared to normal condition. Phenotypic data corresponding to *Pup1* containing genotype in water stress have indicated the performance of root traits thereby making them useful in utilizing in breeding programs.

ACKNOWLEDGEMENT

Authors acknowledge NRRI, Cuttack and OUAT, Bhubaneswar for providing facility and financial support.

REFERENCES

Bernier J, Kumar A, Venuprasad R, Spaner D, Verulkar S, Mandal NP, Sinha PK, Peeraju P, Dongre PR and Mahto RN 2009. Characterization of the effect of a QTL for drought resistance in rice, QTL 12.1, over a range of environments in the Philippines and eastern India. Euphytica 166: 207-217

Chin JH, Gamuyoo R, Dalid C, Bustamam M, Prasetiyono J, Moeljopawiro S, Wissuwa M and Heuer S 2011. Developing rice with high yield under phosphorus deficiency: *Pup1* sequence to application. Plant Physiology 156: 1202-1216

Chin JH, Lu X, Haefele SM, Gamuyao R, Ismail A, Wissuwa

enzymes in Brassica nigra suspension cells. Plant Physiology 90: 1275-1278

Pandit E, Sahoo A, Panda RK, Mohanty DP, Pani DR, Ananadan A and Pradhan SK 2016. Survey of rice cultivars and landraces of upland ecology for phosphorus uptake1(*Pup1*) qtl using linked and gene specific molecular markers. Oryza 53(1): 1-9

Gardner WK, Barber DA and Parbey DG 1983. The acquisition of phosphorus by *Lupinus albus* L. III. The probable mechanism by which phosphorus movement in the soil/root interface is enhanced. Plant and Soil 70: 107-124

Gomez KA and Gomez AA 1984. Statistical procedures for agricultural research (2 ed.). John wiley and sons, New York pp. 680

Heuer S, Lu X, Chin JH, Tanaka JP, Kanamori H, Matsumoto T, Deleon T, Ulat VJ, Ismail AM, Kai M, Takazumi K, Adachi H, Wasaki J, Shinano T and Osaki M 2002. Cloning and characterization of four phosphate transporter cDNAs in tobacco. Plant Science 163: 837-846

Haefele SM and Hijmans R J 2007. Soil quality in rice-based rainfed lowlands of Asia: characterization and distribution. In: PK Aggarwal, JK Ladha, R K Singh, C Devakumar, B Hardy (eds.). Proceedings of the 26th International Rice Research Conference, October 9-12, 2006, New Delhi, India, pp. 297-308

Ismail AM, Heuer S, Thomson MJ and Wissuwa M 2007. Genetic and genomic approaches to develop rice germplasm for problem soils. Plant Molecular Biology 65: 547-570

Lea PJ and Miflin BJ 2011. Nitrogen assimilation and its relevance to crop improvement. In: Foyer C, Zhang H, eds. Nitrogen metabolism in plants in the post-genomic era. Annual Plant Reviews, Vol. 42. West Sussex: Blackwell Publishing Ltd. pp. 1-40

Kottearachchi NS and Wijesekara U.A.D.S.L 2013. Implememtation of Pup1 gene based markers for screening of donor varieties for phosphorus deficiency tolerance in rice. Indian Journal of Plant Sciences ISSN: 2319-3824 (Online) 2013, 2(4): 76-83 October-December

Liu J, Uhde-Stone C, Li A, Vance C and Allan D 2001. A phosphate transporter with enhanced expression in proteoid roots of white lupin (*Lupinus albus* L.). Plant and Soil 237: 257-266

Marschner H 1995. Mineral nutrition in plants, 2nd edn. San Diego: Academic Press

Mucchal US, Pardo JM, Raghothama KG 1996. Phosphate transporters from the higher plant Arabidopsis thaliana. Proceedings of the National Academy of Sciences, USA 93: 10519-10523

Mucchal US and Raghothama KG 1999. Transcriptional regulation of plant phosphate transporters. Proceedings of the National Academy of Sciences, USA 96: 5868-5872

Ni JJ, Wu P, Senadhira D and Huang N 1998. Mapping QTLs for phosphorus deficiency tolerance in rice (*Oryza sativa* L.). Theoretical and Applied Genetics 97: 1361-1369

Olsen SR, Cole CV, Watanabe FS and Dean LA 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular No. 939

Panse VG and Sukhatme PV 1985. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication pp. 87-89

Tadano T and Sakai H 1991. Secretion of acid phosphatase by the roots of several crop species under phosphorus-deficient conditions. Soil Science and Plant Nutrition 37: 129-140

Tyagi W, Rai M and Dohling A 2012. Haplotype Analysis for locus in rice genotypes of north eastern and eastern India to identify suitable donors tolerant to low phosphorus. Sabrao Journal of Breeding and Genetics 44(2): 398-405

Venuprasad R, Dalid CO, Delvalle M, Zhao D, Espiritu M, Stacruz T, Amante M, Kumar A and Atlin GN 2009. Identification and characterization of large effect quantitative trait loci for grain yield under lowland drought stress in rice using bulk-segregant analyses. Theoretical and Applied Genetics 120(1): 177-90

Sarkar RK, D Panda, JN Reddy, SSC Patnaik, DJ Mackill and AM Ismail 2009. Performance of submergence tolerant rice (*Oryza sativa*) genotypes carring the Sub1 quantitative trait locus under stressed and non-stressed natural field conditions. Indian J. Agric. Sci. 79: 876- 883

Wasaki J, Yamamura T, Shinano T and Osaki M 2003a. Secreted acid phosphatase is expressed in cluster roots of lupin in response to phosphorus deficiency. Plant and Soil 248: 129-136

Wissuwa M, Wegner J, Ae N and Yano M 2002. Substitution mapping of *Pup1*: a major QTL increasing phosphorus uptake of rice from a phosphorus

deficient soil. Theor. Appl. Genet. 105: 890-897

Wissuwa M 2003. "How Do Plants Achieve Tolerance to Phosphorus Deficiency: Small Causes with Big Effects." Plant Physiology 133(4): 1947-1958

Yano M and Wissuwa M 2009. Comparative sequence analyses of the major quantitative trait locus phosphorus uptake 1(*Pup1*) reveal a complex genetic structure. Plant Biotechnology Journal 7(5): 456-7

Yi K, Wu Z, Zhou J, Du L, Guo L, Wu Y and Wu P 2005. OsPTF1, a novel transcription factor involved in tolerance to phosphate starvation in rice. Plant Physiology 138: 2087-2096