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Determining critical value of soil *Olsen* P for dry direct seeded rice (*Oryza sativa*) in a greenhouse study in northwestern India

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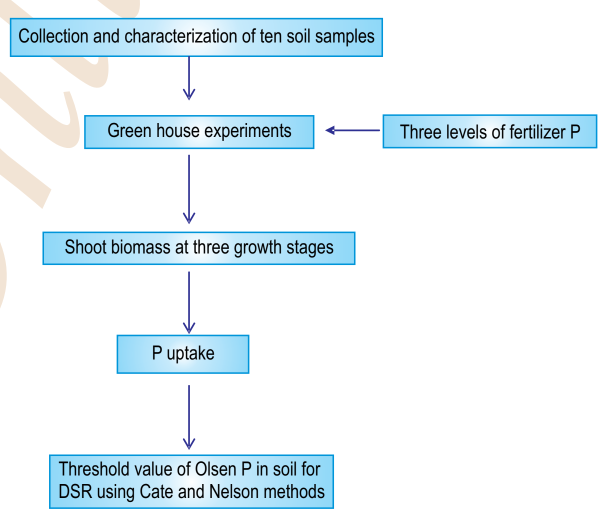
Abstract

Aim: In view of the looming water crisis and shortage of labour during transplanting, dry-seeded rice (DSR) is an attractive option for rice cultivation in Asia. Presently limited information is available on optimum nutrient management in DSR. Compared to puddled transplanted rice, DSR is likely to encounter less availability of fertilizer phosphorus. The main objective of the study was to determine critical value of soil Olsen P for DSR.

Methodology: A greenhouse experiment was conducted to study the effect of three levels of phosphorus (0, 6.5, 13 mg P kg^{-1} soil) application on dry matter accumulation and phosphorus uptake of DSR at maximum tillering (MT), panicle initiation (PI) and flowering stages (FL) in ten different soils varying in Olsen P and texture. Bulk soil samples (0-15 cm) were collected from different locations in Punjab state of India and analyzed for initial physical and chemical properties (pH, electrical conductivity, cation exchange capacity, organic C, $NaHCO_3$–extractable P, NH_4OAc-extractable K, DTPA-extractable Zn, Cu, Mn, and Fe and particle size distribution). Soil samples collected at flowering stage were analyzed for Olsen P. Plant samples were analyzed for total phosphorus content. Cate and Nelson (1971) method was used to determine the critical limit of soil Olsen P.

Results: Soils low in Olsen P ($\leq$5.3 mg kg^{-1} soil) showed significant increase in shoot biomass and phosphorus uptake of DSR with the application of 6.5mg P kg^{-1} soil compared to control. Critical values of Olsen P for DSR, below which the crop would suffer yields determined by Cate-Nelson model, was 9.0 mg kg^{-1}soil. Recovery of phosphorus fertilizer at 6.5 mg P kg^{-1} in different soils ranged from 23.3-42.8%, with lower values for high Olsen P soils compared to control.The critical value of Olsen P was low at initial (MT and PI) growth stages than at flowering stage, suggesting that early crop growth in DSR is more sensitive to phosphorus deficiency.

Interpretation: Response of DSR to phosphorus application depends on the availability of phosphorus in soil. A critical level of Olsen P at 9 mg kg^{-1} soil can be used for applying fertilizer phosphorus to DSR.



Introduction

Most of the rice in Asia is cultivated by transplanting 25 to 30 day-old seedlings into puddled soil (Chauhan, 2012). In view of the looming water crisis and shortage of labour during transplanting, farmers in Asia are considering dry -seeded rice (DSR) as an alternate option for rice cultivation (Pandey and Velasco, 2005; Kumar and Ladha, 2011). Rice soil in aerobic and reduced phases greatly differs in physical and chemical characteristics. In shifting from TPR to dry-seeded aerobic rice, factors such as increased redox potential (Gao *et al*., 2002), pH changes , precipitation of Fe as $Fe(OH)_3$, oxidation of organic matter, and restricted Zn movement towards plant roots due to reduced water contents occur. The practice of puddling in transplanted rice results in destruction of soil agreegates and formation of hardpan at a depth of 150-200 mm beneath the soil surface. There is an adverse effect of puddling on the yield of following wheat (Jat *et al*., 2009). The cultivation of DSR in the northwest Indo-Gangetic Plains provides better opportunity to attain optimal plant density, and high water and labour productivity (Mahajan *et al.,* 2012). Phosphorus deficiency is a major constraint for upland (aerobic) rice production in various soils of the world but the problem may be overcome by phosphorus fertilization along with production of improved genotypes, which could efficiently utilize phosphorus from the soil (George, 2001). Soils (aerobic) under DSR greatly differ in chemical characteristics from that under puddled transplanted rice. The redox potential of aerobic rice systems is known to affect the forms and availability of many nutrients, including phosphorus (Zhang *et al.,* 2009). Compared to puddled transplanted rice, DSR after wheat is likely to encounter the lower availability of fertilizer phosphorus. While phosphorus becomes more available under anaerobic conditions in transplanting rice, changing from anaerobic phase to aerobic phase in DSR increases P fixation and thus reduces its availability. Furthermore, DSR has a higher nutrient requirement as compared to transplanted crop because of high plant density and greater production of biomass in the vegetative phase (Hartinee *et al.,* 2010). Soil chemical analysis is a principal tool for evaluation of soil fertility. The fertilizer dose to be applied to soil is mainly based on the diagnosis of the nutrient availability in soil. A recent literature review has reported that phosphorus availability prediction has been extensively studied over the last decades (Singh *et al.,* 2003). The critical value of soil Olsen P is likely to differ for DSR from that for flooded transplanted rice.

Critical value of soil Olsen P is generally considered as available phosphorus above which the probability of crop yield response to fertilizer phosphorus application is small or nil (Mallarino and Blackmer, 1992). Several methods have been used to measure the critical values including fitting Mitscherlich type exponential, quadratic polynomial or two linear split equations (Cate and Nelson, 1971; Johnston *et al*., 1986; Bollons and Barraclough, 1999; Colomb *et al*., 2007). The Cate and Nelson (1971) is based on the application of different rates of phosphorus fertilizer in a series of soils differing in soil phosphorus supply and other soil properties and fitted by using relative yield values in order to reduce the scatterness in data sets. The present greenhouse study was carried out to evaluate the response of DSR to P fertilizer in different soils varying in Olsen P and to establish the critical value of Olsen P for DSR.

Materials and Methods

A greenhouse experiment was conducted to study the effect of three levels of P (0, 6.5, 13 mg P kg^{-1} soil) application on dry matter accumulation and phosphorus uptake of DSR at maximum tillering, panicle initiation and flowering stages in ten different soils varying in Olsen P and texture. Bulk soil samples (0-15 cm) were collected from different locations in Punjab state of India and analyzed for initial physical and chemical properties using standard analytical methods (Table 1). After air drying, soil samples were ground and passed through 0.5 mm sieve. Phosphorus fertilizer as mono ammonium phosphate was applied to designated pots. Basal dose of nitrogen (75mg N kg^{-1} soil) as urea, K (25 mg K kg^{-1} soil) as potassium chloride and zinc (30 mg Zn kg^{-1} soil) as zinc sulphate was mixed into the pre-weighed soil. The treatments were replicated thrice. Each pot (height and diameter 20 cm each) was filled with 4 kg of soil. Separate pots were used for soil and plant sampling at three growth stages. There were thus 27 pots for each soil. The pots were arranged in greenhouse in a completely randomized block design (CRD).

At field capacity*,* 10-12 seeds of rice (cultivar PR 114) were sown and five seedlings were maintained after establishment in each pot. In order to ameliorate iron deficiency, the crop was sprayed with 1% solution of ferrous sulphate three times (5 sprays for loamy sand soil) at weekly interval starting from 20 days after seeding. All the pots were watered to maintain soil moisture at approximately field capacity throughout the growing season. At three growth stages shoots were harvested from the ground surface from each pot. At flowering stage, roots were also removed from each pot and then soil samples were collected to determine Olsen P content.

Soil analysis : Initial soil samples were ground to pass through a 2 mm sieve, processed and analyzed for pH, electrical conductivity (EC), cation exchange capacity (CEC), organic C (Walkley and Black, 1934), $NaHCO_3$–extractable P (Olsen *et al.,* 1954), NH4OAc-extractable K (Merwin and Peech, 1950) and particle size distribution (Day, 1965). The USDA textural triangle was used for determining the textural class. For DTPA-extractable metal fractions, 10 g of soil sample was treated with 20 ml of DTPA extractant [0.005M DTPA + 0.01M calcium chloride ($CaCl_2$) + 0.1M triethanolamine, adjusted to pH 7.30] (Lindsay and Norvell, 1978). Filtrates were analyzed for Zn, Cu, Mn, and Fe by atomic absorption spectrophotometer and reported on an oven-dry-weight basis. Soil samples collected at flowering stage were air dried ground and passed through a 2 mm sieve and analyzed for Olsen P (Olsen *et al*., 1954).

Plant analysis : Plant samples were thoroughly washed with water and then with distilled water. Roots extracted from the pots were washed 4-5 times with tap water to remove soil particles and then with distilled water. Plant and root samples were oven dried at 65±1^{O}C, ground to pass through 0.5 mm stainless steel sieve and stored in polythene bags. Total phosphorus analysis in shoot and root was estimated spectrophotometrically by vanado-molybdo phosphoric acid method (Sparks *et al.,* 1996).

Statistical analysis : Analysis of variance (ANOVA) was carried out for the data on the biomass accumulation, P concentration, and P uptake in soil using completely randomized design. Least significance difference (LSD) at a 0.05 level of probability was used to test the significance of differences among treatment means. Cate and Nelson (1971) model was used to determine the critical limit of soil Olsen P by plotting relative dry matter yield (Y-axis) at 6.5 mg P kg^{-1} at FL against initial soil Olsen P values (X-axis).

Results and Discussion

Dry matter yield, P uptake and P recovery by DSR : At all the three growth stages, significant soil × P interaction effect was observed on shoot dry matter yield. Therefore, simple effects of soil and P rate are discussed. Dry matter yield of DSR increased significantly with the application of 6.5 mg P kg^{-1} soil over control on soils testing low in Olsen P ($\leq$ 5.2 mg P kg^{-1}) at all the three growth stages (Fig. 1A, 1B and 1C). However, dry matter yield at flowering stage also increased significantly with P application in soils S4 and S5 having Olsen P between 7.0 and 7.5 (Fig. 1C). It was observed that application of 13 mg P kg^{-1} soil did not cause significant increase in dry matter production over application of 6.5 mg P kg^{-1} soil at all the growth stages (Fig. 1A, 1B and 1C). Dry-seeded rice produced significantly higher dry matter yield on soils testing medium and high in Olsen P than that on low P soils at all the three growth stages (Fig. 1A, 1B and 1C). On an average, soil testing medium in Olsen P (S4-S7) produced 70.2 %, 104.7% and 59.2% higher dry matter as compared with low P soil at maximum tillering (Fig. 1A), panicle initiation (Fig. 1B) and flowering stages (Fig. 1C), respectively. When phosphorus fertilizer (6.5 mg kg^{-1}) was applied, the corresponding increase in dry matter yield was less (19.3 %, 25.9% and 32.2%, respectively). The data suggest that soil phosphorus supply limited the growth of DSR on low phosphorus soils. Another reason for higher dry matter yield on medium and high phosphorus soils as compared to low phosphorus soils could be their better soil quality (organic C, available K and DTPA-Fe contents). Baggie *et al.,* (2004) observed that phosphorus application significantly increased shoot weight of upland rice at panicle initiation stage on acid soils low in available phosphorus. Mahmood *et al*., (2015) reported that upland DSR requires high amount of phosphorus (120 kg P_2O_5 ha^{-1}) when the crop residues were removed, particularly on saline soils. In another study, Sanusan *et al*., (2009) reported that optimum rate of phosphorus fertilizer for DSR was 60 kg P_2O_5 ha^{-1} in rain-fed conditions. However, transplanted rice did not respond to phosphorus fertilizer when followed by wheat receiving recommended dose of 60 kgP_2O_5 ha^{-1} in the rice-wheat system (Singh and Singh, 2001). Brar and Bhullar (2013) reported that utilization of phosphorus by rice grains and straw in DSR was similar to transplanted rice.

Total phosphorus uptake of DSR showed significant soil by P level interaction effect at maximum tillering and panicle initiation stage (Fig. 2A and 2B). While, interaction of soil and P level was not significant and therefore effect on P uptake was not observed at flowering stage (Fig. 2C). Plant phosphorus uptake at maximum tillering and panicle initiation stage increased significantly in the soil S1 to S4, when 6.5 mg P kg^{-1} soil was added to them (Fig. 2A and 2B). Similarly, significant increase in dry matter yield due to phosphorus application was observed up to 6.5 mg Olsen P kg^{-1} soil at flowering stage which increased the mean dry matter yield by 28.1% over control. Further, addition of phosphorus (13 mg P kg^{-1} soil) could not induce significant change in phosphorus uptake. Like dry matter yield, average phosphorus uptake in soils categorized as medium in Olsen P (S5-S8) over those categorized as low phosphorus was 79 % and 115.5%, respectively higher at maximum tillering and panicle initiation stage when no phosphorus was applied, respectively. The corresponding increase in phosphorus uptake at 6.5 mg P kg^{-1} was 20.4 % and 27.1 %. Average phosphorus uptake values in different soils at flowering stage ranged from 21.5 to 42.1 mg P per pot (Fig. 2c). The values were significantly higher for soils with high in Olsen P content (> 10 mg P kg^{-1}) than in low and medium phosphorus soils. The average phosphorus uptake on medium and high Olsen P soils compared to low phosphorus soils was 38.2% and 53.7% at P0 level, and 22.2% and 31% at 6.5 mg P kg^{-1}, respectively.

Baggie *et al.* (2004) reported that phosphorus uptake in upland rice shoots increased significantly on phosphorus application in low phosphorus soils and in significant increase occurred with further application of phosphorus fertilizer. Sahrawat (2008) reported that shoot biomass and shoot phosphorus uptake showed linear response to the addition of phosphorus fertilizers up to 60 kg P ha^{-1} level and further increase in rice yield with increase in phosphorus rate was non significant. At flowering stage, root biomass increased significantly with the increase in initial level of available phosphorus content in soil (Table 2). Dry-seeded rice on soils with initial Olsen P level $\geq$ 8.7 mg kg^{-1} (S7-S10) had significantly higher root biomass than on soils with initial P level $\leq$ 6.1 mg kg^{-1}. Application of 6.5 mg P kg^{-1} soil increased the root biomass by 15.1% over control. Like shoot dry biomass, no further increase in root biomass was observed by increasing the fertilizer phosphorus rate to 13 mg P kg^{-1}.

Root phosphorus content at flowering stage in different soils ranged from 4.37-8.18 mg phosphorus per pot. Like

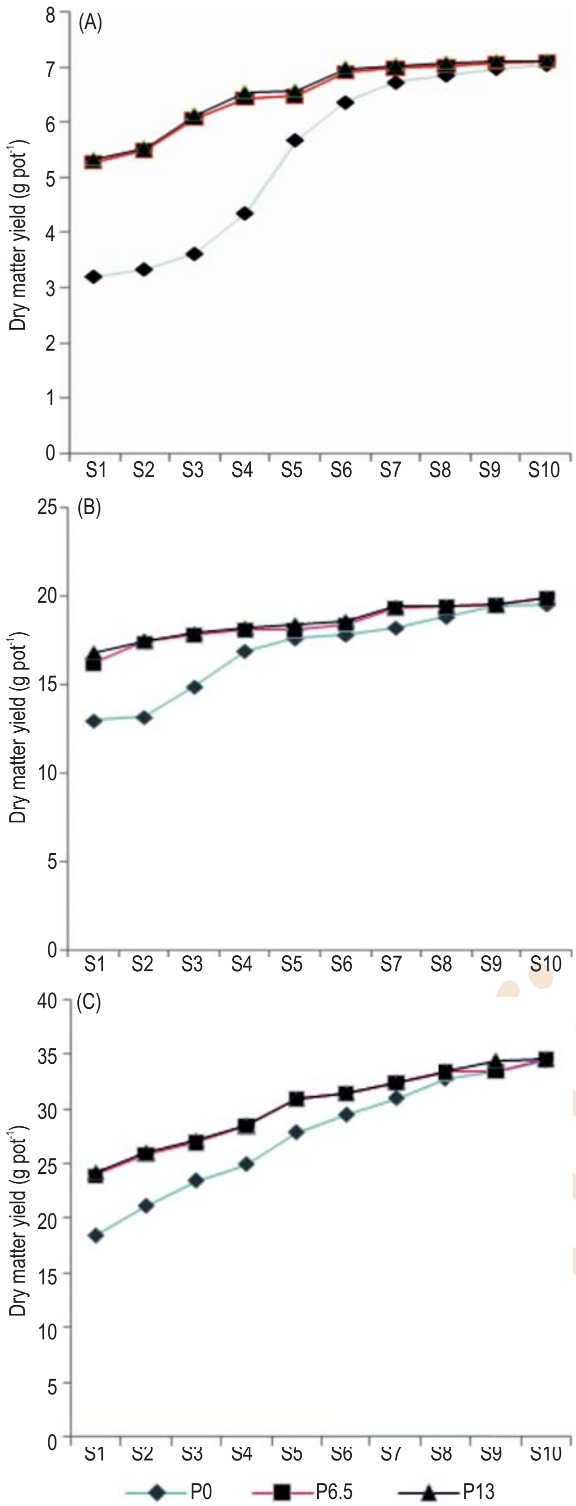


Fig. 1 : Dry matter yield of DSR at (A) maximum tillering, (B) panicle initiation and (C) flowering growth stages

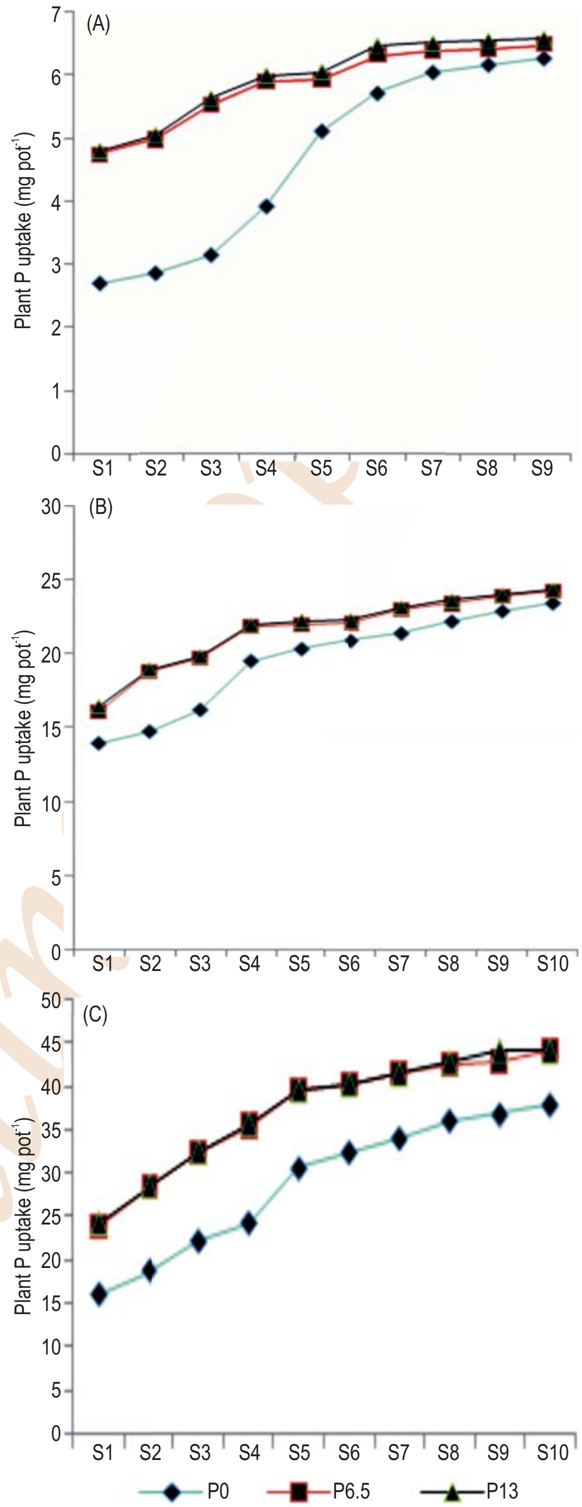


Fig. 2 : Plant P uptake of DSR at at (A) maximum tillering, (B) panicle initiation and (C) flowering growth stages

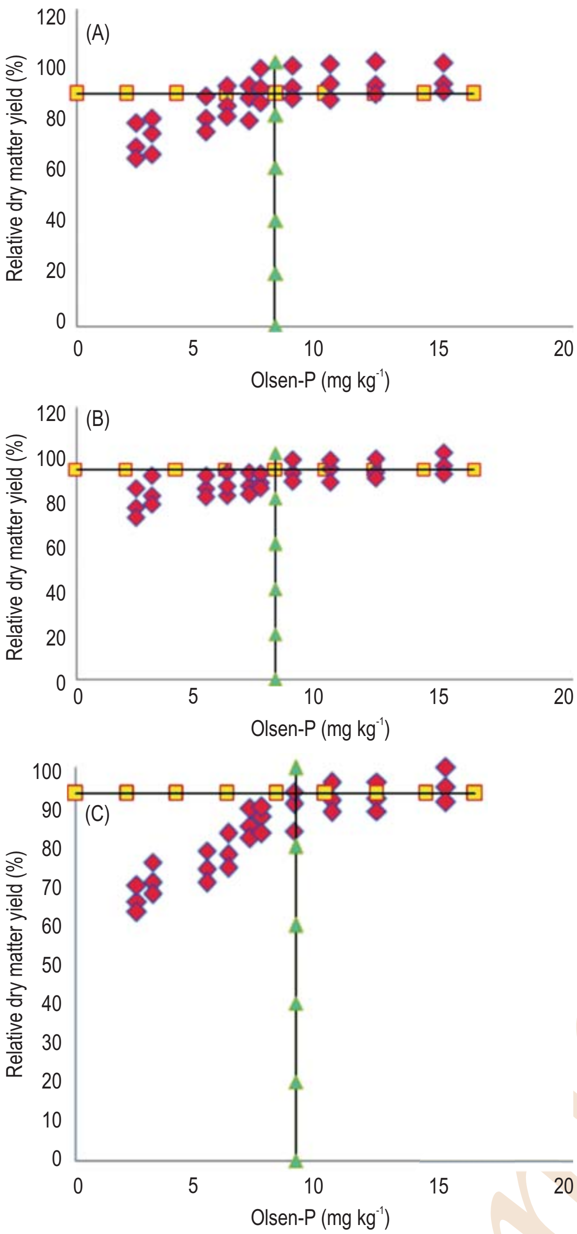


Fig. 3 : Cate -Nelson graphic analysis relating Olsen-P at (A) maximum tillering, (B) panicle initiation and (C) flowering growth stages with relative dry matter yield

phosphorus uptake in shoots, phosphorus uptake in roots increased significantly (9.3%) with the application of 6.5 mg P kg^{-1}, irrespective of soil type (Table 2). The phosphorus uptake in rice roots was significantly higher in soils with Olsen P$\geq$ 7.4 mg P kg^{-1} (S6 to S10) than in soil with Olsen P $\leq$ 6.7 mg kg^{-1} (S1-S4). Among different root and shoot parameters, shoot dry weight was the most sensitive parameter for studying response to fertilizer phosphorus in DSR. Recovery of applied phosphorus at 6.5 mg P kg^{-1} was calculated from the shoot P uptake data collected at flowering stage of DSR. Phosphorus recovery by DSR was higher (28.7 to 42.8%) in soils with Olsen P content $\leq$8.7.1 mg P kg^{-1} than in other soils with high Olsen P content (23.3-25.5%) (Table2). The phosphorus recovery values for DSR are higher than that reported (20-25%) for other crops (Singh and Singh, 2001). However, phosphorus recovery values for 13 mg P kg^{-1} was much lower (about 50%) compared to that for 6.5 mg P kg^{-1} due to small increase in biomass yield and phosphorus uptake.

Critical level of Olsen P for DSR : Critical levels of Olsen P for three growth stages of DSR were calculated using the Cate-Nelson model. Relative dry matter yield of 88% for maximum tillering, 92.5% for panicle initiation and 93.3 % for flowering stage were taken as horizontal critical level because treatment yields higher than that did not differ significantly at P=0.05 probability level. The Cate-Nelson plot showed that critical values for soil Olsen P for maximum tillering and panicle initiation stages were 8 mg kg^{-1}, while it was 9 mg kg^{-1} for panicle initiation (Fig. 3A, 3B and 3C). The data suggested that the critical value of Olsen P was somewhat lower at initial (MT and PI) growth stages than that at flowering stage suggesting that early crop growth in DSR is more sensitive to phosphorus deficiency. A critical level of Olsen P at 9 mg kg^{-1} might be optimum for making fertilizer phosphorus recommendation to DSR. A critical level of Olsen P for DSR was lower than 14.5 mg kg^{-1} reported for the flooded transplanted rice (Rahman *et al*., 1995) and 15.3-16.3 mg kg^{-1} was reported for wheat and maize (Tang *et al*., 2009). However, Linquist and Ruark (2011) reported a critical level of soil Olsen P as 6 mg kg^{-1} for flooded direct seeded rice**.** Kalala *et al.* (2016) reported that critical level for response of P was 8.0 mg P kg^{-1} for rice. A positive response in DSR to phosphorus was obtained when soil test phosphorus was less than 7 mg kg^{-1} at all the sites. On the other hand, Semoka and Mnguu (2000) showed that critical soil phosphorus level for Olsen method was 20 mg kg^{-1}. A critical level of 17 mg P kg^{-1} (Olsen P) was determined for rice production in the Senegal river valley of west Africa (Bado *et al*., 2007) and phosphorus fertilizer applications are recommended when soil extractable phosphorus decreases below this critical level.

Soil receiving no application of phosphorus fertilizer exhibited a decrease in Olsen P content over initial level (Table 2). A higher decrease in Olsen P was recorded in soils testing high in available phosphorus as compared to the soils with low phosphorus status. The absorption of soil phosphorus by rice crop lowered Olsen P in soils. Since crop P uptake was much higher in high P soils, which experienced greater decrease than the low P soils. On the other hand, application of fertilizer phosphorus caused significant increase in the Olsen P content over the initial levels, irrespective of soil type. The increase in the concentration of Olsen P was 71% and 266 % with the application of 6.5 and 13 mg P kg^{-1} over soils receiving no phosphorus fertilizers. Singh and Singh (2001) reported large build up in Olsen P with phosphorus application.

Table 1 : Physico-chemical properties of soils used in the study

Property	Soil sample number									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
pH (1:2)	7.70	7.24	8.11	7.33	7.44	7.80	6.90	7.70	7.38	8.00
EC (dSm^{-1})	0.38	0.21	0.40	0.26	0.19	0.63	0.20	0.30	0.37	0.23
Organic C (%)	0.59	0.20	0.62	0.52	0.32	0.80	0.67	0.39	0.54	0.60
Avail. K (mg kg^{-1})	63	33	37	37	32	220	73	130	115	83
Olsen-P (mg kg^{-1})	2.4	3.1	5.2	6.1	7.0	7.4	8.7	10.2	12.1	14.8
CEC (c mol (p^+) kg^{-1})	6.93	5.63	7.46	6.24	6.63	7.97	6.93	6.68	7.71	7.75
DTPA- extractable micronutrients (mg kg^{-1})										
Fe	16.1	6.2	16.4	7.0	4.7	21.3	24.9	16.3	24.0	21.1
Cu	2.2	4.9	1.8	0.6	0.3	2.3	1.7	1.1	1.3	1.3
Zn	1.0	1.4	1.6	2.7	2.4	1.8	3.4	2.0	3.3	3.3
Mn	8.0	6.3	8.6	8.3	8.7	7.7	12.5	6.1	9.4	5.6
Particle size distribution										
Sand (%)	26	89	47	80	86	42	53	73	66	76
Silt (%)	44	3	33	8	4	36	17	13	14	10
Clay (%)	30	8	20	12	10	22	30	14	20	14
*Textural class	CL	LS	L	SL	LS	L	SCL	SL	SCL	SL

*S- Sand; C- Clay; L- Loam

Table 2 : Root biomass, root P uptake and Olsen P content in different soils as affected by phosphorus application at flowering stage of DSR

Treatment	Root biomass(g per pot)	Root P (g per pot)	P recovery efficiency (%)	Soil Olsen P (mg kg^{-1})
Soil				
S1	8.97	4.37	29.5	3.92
S2	9.86	4.77	36.5	4.40
S3	10.67	5.59	38.7	4.64
S4	11.00	6.30	42.8	4.97
S5	11.47	6.72	34.5	5.19
S6	11.87	7.29	30.0	5.31
S7	12.15	7.52	28.7	5.60
S8	12.53	7.76	25.5	6.50
S9	12.67	7.94	23.3	6.95
S10	12.72	8.18	24.3	8.62
LSD (P=0.05)	0.75	0.46	-	2.41
P levels (mg P kg^{-1})				
0	10.33	6.23	-	2.65
6.5	11.89	6.81	-	4.54
13	11.96	6.89	-	9.64
LSD (P=0.05)	0.41	0.25	-	1.32

A threshold value of Olsen P for DSR was established for which no information was available earlier. The study showed that DSR responded significantly to phosphorus fertilizer application at 6.5 mg P kg^{-1} in the soils having Olsen P content below <7.0 mg kg^{-1} soil. A threshold value of Olsen P for DSR was found to be 9 mg kg^{-1} soil using Cate and Nelson technique. The recovery of phosphorus by DSR was quite high when phosphorus fertilizer was applied at 6.5 mg kg^{-1} on soils testing low in Olsen P.

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