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Full Length Article

Response of Direct Seeded Rice and Wheat Crops to Phosphorus Application with Crop Residue Incorporation in Saline-Sodic Soil

Imdad Ali Mahmood* and Arshad Ali
Land Resources Research Institute, National Agricultural Research Centre, Park Road, Islamabad-45500, Pakistan
*For correspondence: imdad20260@yahoo.com

Abstract

A long term field study using permanent layout was conducted to investigate the effect of P application (0, 40, 80, 120 kg P_2O_5 ha^{-1}) with and without crop residue (CR) incorporation on growth and yield of direct seeded rice (DSR) and wheat crop under saline-sodic soil (EC_e = 6.63 dS m^{-1}; pH_s = 8.31; SAR = 17.39 ($mmol_c$ $L^{-1})^{1/2}$; $CaCO_3$ = 3.47%; Extractable P = 3.92 mg kg^{-1}; sandy loam) during growth seasons 2011 and 2012 at Soil Salinity Research Institute (SSRI) Farm, Pindi Bhattian. The experiment was planned employing split plot design with three replications. Planting methods (with and without crop residue incorporation @ 2 ton ha^{-1}) for both DSR and wheat crop were kept in main plots and P application was in sub plots. Data on tillering, plant height, panicle length, paddy and straw yields was collected from both rice and wheat crops. On an average of two year DSR data, maximum tillers (16), panicle length (27), grain $panicle^{-1}$ (89) and paddy yield (2.75 t ha^{-1}) was produced with P application @ 80 kg P_2O_5 ha^{-1} along with CR incorporation, which was considerably better (13%) than that of P application @ 120 kg P_2O_5 ha^{-1} without CR incorporation. A significant increase (22% and 19%) over control in paddy and wheat grain yields, respectively was observed with 80 kg P_2O_5 ha^{-1} application along with CR incorporation. Overall, continuous two year CR incorporation further increased 9% paddy during the follow up year of crop harvest as compared to without CR incorporation. Maximum wheat grain yield (2.84 t ha^{-1}) was harvested with 80 kg P_2O_5 ha^{-1} + CR and was significantly higher than grain yield (2.68 t ha^{-1}) receiving 120 kg P_2O_5 ha^{-1} without CR incorporation. Higher concentrations of P, K and Ca^{2+} in plant tissues (rice and wheat) were found where P was applied @ 80 kg P_2O_5 ha^{-1} along with CR incorporation or 120 kg P_2O_5 ha^{-1} alone while Na^+ and Mg^{2+} concentration decreased with increasing the rate of P. Overall, an increasing trend in paddy yield of DSR was observed with increasing the rate of P application without CR incorporation during both the cropping years.

Keywords: Saline-sodic soil; Direct seeded rice; Wheat crop; P application; Crop residue incorporation; Ionic concentration; Growth and yield

Introduction

Rice is the premier food grain crop among cereals for household utilization and export occupying an area of over 2.31 million hectare (m ha) and production 5.54 million ton with 2.7% of the value added in agriculture and 0.6% of GDP. Average rice paddy yield (2398 kg ha^{-1}) in the country is nearly three to four times lower than other rice producing countries of the world (Economic Survey, 2013). Among factors responsible for its low yield in rice-wheat cropping system are water shortage, escalating fuel and high fertilizer costs (particularly of P fertilizers) and labor shortage during rice transplanting. Besides, soil salinity and sodicity is another major constraint to increase crop yields. About half of the rice cultivated area (~ 1.0 mha) in the Punjab, Pakistan is salt-affected which has moderate to high salinity, high pH and shortage of good quality ground water causing 30-70% paddy yield reduction (Qayyum and Malik, 1988; FAO, 2011; NFDC, 2012). Moreover, Phosphorus (P) availability in soluble orthophosphate form is a widespread constraint under calcareous soils because it makes insoluble dibasic calcium phosphate dehydrate ($CaHPO_4 \cdot 2H_2O$), octacalcium phosphate (Ca_4H $(PO_4)_3 \cdot 3H_2O$), and hydroxyapatite (Ca_{10} $(PO_4)_6$ $(OH)_2$. The formation of each product decreases P solubility and upon flooding plant available P is not released from these products. Although, a large proportion of applied P in the soil becomes immobile due to this process (Rahmatullah *et al*., 1994), however, the plants readily utilize only 8-33% of applied P in the first growing season (Saleem *et al*., 1986). The high concentration of calcium in the soil results in precipitation of insoluble calcium phosphate compounds for a short time and reduces P availability (Chhabra and Thakur, 2000). In alkaline soils, most of the soil P is found in the form of soluble sodium phosphate compounds (NaH_2PO_4) that are absorbed by the plants causing reduction in plant growth and crop yields due to excess Na uptake despite of P fertilization (Mahmood *et al*., 1994; Aslam *et al*., 2008; Mahmood *et al*., 2013). Saline soils contain excess soluble salts (Cl^- and SO_4^{--} of Na^+, Ca^{2+} and Mg^{2+}) which cause high

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osmotic pressure and complex interaction of Na, Ca and K disturb equilibrium in rhizosphere that effect plant growth (Murtaza *et al.*, 2013). P availability is affected due to anion competition (PO_4^{-} and Cl^-) and precipitation of applied P and its fixation. Further phosphorus requirement increases in problem soils to get optimum yields because under unfavorable soil environments its nature and availability are changed (Mahmood *et al*., 2000; Slaton *et al*., 2002; Hussain *et al*., 2003). Proper P nutrition is critical for producing maximum paddy yields because it encourages healthy growth, development of strong root system, maximum tillering, uphold more flowering and seed formation (Sainio *et al*., 2006). Often, P deficiency in rice is referred to as a "hidden hunger" which causes poor tillering, slow leaf canopy expansion, poor grain formation and delayed maturity. More than 90% Pakistani soils are deficient in P and its availability to the crops (NFDC, 2010). In spite of this, average use of phosphatic fertilizers for all crops is generally low and imbalance fertilizer use (N: P ratio ~ 5: 1) is a usual under farmer's practices (Nisar *et al*., 1992; NFDC, 2012) as compared to other developing countries (Mutert and Fairhurst, 2002). Phosphorus availability under non-flooded conditions might be higher due to comparatively less precipitation of insoluble Ca phosphate compounds with normal irrigations and its requirement for dense crops also seems to be reasonably high (Hussain *et al*., 2003; Byous *et al.,* 2004; Sainio *et al*., 2006).

Crop residues are source of plant nutrients, organic material and an important constituent for soil health and the stability of agricultural ecosystem. About 25% of N and P, 50% of the S, and 75% of K uptake by cereal crops are retained in crop residues, making them valuable nutrient sources. Since large portion of plant nutrients taken up by plants remains in the straw, much of this can be recycled for subsequent crop growth after its decomposition (Byous *et al.,* 2004). In many studies, recycling of crop residues is reported to increase the organic carbon, nutrient contents, increased crop yields (Misra *et al*., 1996; Eagle *et al*., 2000; Krishna *et al*., 2004; Ali *et al*, 2012; Mahmood *et al*, 2013).

Direct seeding of rice is suitable technology for resource poor farmers of salt-affected lands for which transplanting labor cost, water and machinery tools expenses required during puddling and transplanting could be saved in addition to timely sowing. Arshadullah *et al*. (2007) reported a significant difference in paddy yield of direct seeded rice and traditionally transplanted rice indicating relatively higher economic return, when rice was planted directly through seed in a salt-affected field as compared to seedling transplanting (2, 3 or 4 seedlings hill^{-1}). The crop matures early as compared to traditional transplanting, which further facilitate timely sowing of wheat after rice harvest under rice-wheat cropping system. In spite of these benefits, there is much more plant population under direct seeded rice as compared to transplanted rice for which nutrients requirement could also be higher to produce potential yields (Mishra *et al.,* 2005; Arshadullah *et al.,* 2007). Little information is available regarding nutrient management particularly of P application for DSR in saline-sodic soils. Therefore, any measure through, which the healthy crop stand could be obtained from salt-affected lands with economical inputs, would be a step forward to improve the yields. Keeping all these factors, present study was planned to investigate the P dose for DSR and following wheat under rice-wheat cropping system along with crop residue incorporation and their impact on crop yields in a saline-sodic soils.

Materials and Methods

A long term field experiment was conducted to investigate the effect of P application with and without CR incorporation on DSR and subsequent wheat yields in a permanent layout under saline-sodic soil (sandy loam) having EC_e = 6.63 dS m^{-1}, pH_s = 8.31, SAR = 17.39 (mmol$_c$ L^{-1})$^{1/2}$, $CaCO_3$ = 3.47% and extractable P = 3.92 mg kg^{-1} of rice-wheat cropping system at Soil Salinity Research Institute (SSRI) Farm, Pindi Bhattian during 2011 and 2012. The experiment was designed employing split plot with three replications. For both crops planting methods i.e., with and without CR incorporation @ 2 ton ha^{-1} and P application were put into main- and sub-plots, respectively. The treatments for each sub plot were control (no P application) and phosphorus applied at 40, 80 and 120 kg P_2O_5 ha^{-1}.

Recommended basal dose of N @ 100 kg ha^{-1} as urea was applied in two splits (half at sowing time and remaining half at tillering stage) and K @ 50 kg ha^{-1} as SOP was applied to all plots at the time of sowing. Soaked seed (for 24 h) of rice cv. Super-2000 @ 40 kg ha^{-1} was broad casted uniformly. The same inputs were applied to intermediate wheat crop. Effective weedicides were used to control weeds and the crops were grown to maturity. All agronomic requirements and plant protection measures were met throughout the growth periods whenever required. Pre sowing soil samples (0-15 and 15-30 cm depth) were collected for the analysis of general soil characteristics (Table 1) according to the methods suggested by Ryan *et al*. (2001). The whole plant samples from both (DSR and wheat) were collected at maturity for the determination of ionic concentration in their tissues. Dried and ground samples were digested in perchloric-nitric acid (2:1 N) mixture (Rhoades, 1982) to estimate P, K, Na^+, Ca^{2+} and Mg^{2+} by spectronic-20 and atomic absorption spectrophotometer. At maturity, the crops were harvested and agronomic data on fertile tillers, plant height, panicle length, grains panicle^{-1}, paddy/grain and straw yields were recorded. The data collected were subjected to statistical analysis using software package MSTAT-C and treatment means were compared using least significant difference (LSD) at 5% probability level (Gomez and Gomez, 1984).

Results

Agronomic and Yield Traits of DSR

During the first year, maximum fertile tillers, panicle length, grains per panicle and paddy yield (2.63 t ha^{-1}) was recorded with 80 kg P_2O_5 ha^{-1} P applied along with CR incorporation, which was and were improved but statistically similar with 120 kg P_2O_5 ha^{-1} applied P without CR incorporation (Table 2). Similar trend was observed during the second cropping year (2012) but yield response of DSR with CR incorporation was considerably better than previous year crop harvest (2011). Conversely, when P was applied without CR incorporation, higher paddy yield was obtained with increasing the rate of P i.e. 120 kg P_2O_5 ha^{-1} but was significantly less than 80 kg P_2O_5 ha^{-1} applied with CR incorporation. On average of two years, the percent increase in paddy yield over control was 22% with 80 kg P_2O_5 ha^{-1} and CR incorporation. Overall with continuous two year CR incorporation further increase in paddy yield was 9% during the following year of crop harvest as compared to without CR incorporation.

Growth and Yield of Wheat

Maximum fertile tillers, spike length, grain per spike and grain yield (2.83 t ha^{-1}) was produced with P application @ 80 kg P_2O_5 ha^{-1} along with CR incorporation. On the other hand, when P was applied without CR incorporation, higher wheat grain yield was obtained with increasing the P rate to 120 kg P_2O_5 ha^{-1} but less than for 80 kg P_2O_5 ha^{-1} with CR incorporation (Table 3). On average of two years, the percent increase in grain yield over control was 19% with 80 kg P_2O_5 ha^{-1} and CR incorporation. Crop residue incorporation appreciably contributed to growth and yield of wheat grown after DSR.

Ionic Concentration in DSR and Wheat Crops

High Na^+ and low K^+ and Ca^{2+} concentrations in rice plant tissues were found under saline-sodic soil, while the Mg concentration in plant tissues was non-significant during the second cropping year (Table 4 and 5). Maximum Na^+ concentration was found in control when no P was applied with or without CR, while K^+ and Ca^{2+} contents decreased due to P application as well as CR incorporation. Similar trend was found in case of intermediate wheat crop. Crop residue incorporation particularly with P application decreased considerably Na^+ contents and increased K^+ and Ca^{2+} concentrations in plant tissues. The data indicates that P application even at lower rate along with CR incorporation performed statistically equal to higher dose of P without CR incorporation.

P Uptake by DSR and Wheat Crops

During 2011, maximum P uptake (17.6 kg ha^{-1}) by both DSR and wheat crops was found with CR incorporation and P application of 80 kg P_2O_5 ha^{-1}, which further increased (9%) during 2012 and was comparable with higher dose of 120 kg P_2O_5 ha^{-1} without CR during both cropping years (Fig. 1). Under CR incorporation, further increase in P application (120 kg P_2O_5 ha^{-1}) did not showed significant distinction in the uptake of P by both the crops. On the other hand, when P was applied without CR incorporation, maximum P uptake was determined when higher P dose (120 kg P_2O_5 ha^{-1}) was applied and was statistically at par with lower dose of P (80 kg P_2O_5 ha^{-1}) along with CR incorporation.

Table 1: Physico-chemical analysis of the soils before crop sowing

Parameters	Unit	Values	
		0-15 cm	15-30 cm
pH	–	8.31	8.22
ECe	dS m^{-1}	6.63	5.99
SAR	–	17.39	11.97
OM (Walklay Black)	%	0.32	0.21
Total N	%	0.036	0.015
NO_3-N (AB-DTPA)	ppm	2.24	1.98
Total P (Olsen)	ppm	6.78	8.81
Extractable P (AB-DTPA)	mg kg^{-1}	3.92	2.63
Extractable K (AB-DTPA)	mg kg^{-1}	42.06	39.63
Na	mg kg^{-1}	568	286
Ca + Mg	me L^{-1}	4.01	2.16
$CaCO_3$	%	3.47	3.58
HCO_3	me L^{-1}	2.10	1.81
Sand	%	60	
Silt	%	30	
Clay	%	10	
Textural Class	–	Sandy Loam	
Soil Series	–	Rasulpur	

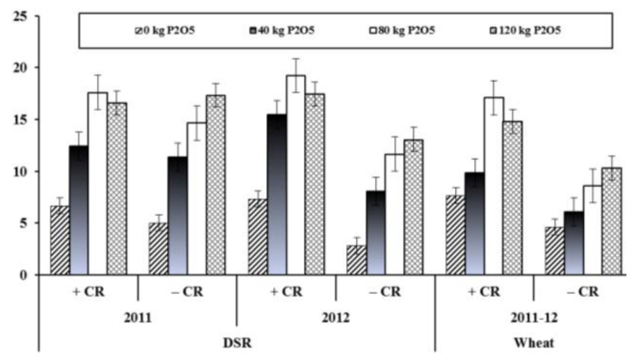

Fig. 1: Total P uptake (kg ha^{-1}) by DSR and wheat as influenced by P application and CR incorporation in saline-sodic soil

Discussion

Direct seeding of rice is being adopted on extensive scale in district Hafizabad, where farmers are facing water shortage, escalating diesel prices and electricity shortage for pumping water and labour shortage as well. The DSR comparatively require more plant nutrition

Table 2: Growth and yield response of DSR as influenced by P application and CR incorporation in saline-sodic soil

P_2O_5 (kg ha^{-1})	Tillers		Plant height (cm)		Panicle length (cm)		Grain per Panicle		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR
							2011					
0	9.00 cd	6.33 d	97.33 abc	89.33 d	21.33 bcd	16.33 de	78.67 c	68.33 e	2.11 c	1.287 e	5.65 bc	3.59 e
40	12.67 b	7.33 d	99.00 ab	91.33 cd	22.67 abcd	18.33 d	81.00 bc	72.33 d	2.39 abc	1.653 d	5.93 ab	4.70 d
80	15.67 a	11.33 bc	99.67 a	93.00 bcd	25.67 a	20.67 cd	87.33 a	79.00 c	2.63 a	2.153 bc	6.02 a	5.42 c
120	14.00 ab	13.00 ab	99.33 a	95.67 abcd	24.33 abc	24.33 ab	84.33 ab	85.67 a	2.47 a	2.430 ab	5.93 ab	5.54 c
LSD	2.13		6.86		3.66		5.06		0.32		0.33	
							2012					
0	9.67 d	5.67 e	106.67 b	87.00 d	24.33 ab	15.33 de	79.33 d	51.67 e	2.40 bc	1.40 e	6.05 a	3.69 d
40	11.33 cd	12.00 cd	114.67 a	92.67 cd	25.33 ab	18.00 d	85.67 bc	77.33 d	2.42 bc	1.71 d	6.16 a	4.37 c
80	16.67 a	13.33 bc	116.67 a	96.67 bc	28.33 a	19.33 cd	91.33 a	81.33 cd	2.87 a	2.17 c	6.24 a	5.27 b
120	15.67 ab	15.67 ab	115.33 a	102.33 b	27.00 a	22.67 bc	87.67 ab	83.00 bcd	2.53 b	2.44 bc	6.16 a	5.64 ab
LSD	3.19		4.50		4.071		5.76		0.32		0.70	

Table 3: Growth and yield of wheat as influenced by P application and CR incorporation in saline-sodic soil

P_2O_5 (kg ha^{-1})	Tillers		Plant height (cm)		Spike length (cm)		Grain per Spike		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR
0	9.00 b	5.33 d	77.33 abc	68.33 d	10.33 cd	5.33 e	34.33 c	26.33 d	2.39 b	1.69 d	4.35 ab	2.96 c
40	10.00 ab	7.00 c	78.00 ab	71.67 c	11.33 bc	8.67 d	37.67 bc	33.33 c	2.55 ab	1.96 c	4.52 ab	3.82 b
80	11.33 a	9.33 b	79.67 a	72.33 bc	14.00 a	11.00 c	42.67 a	35.33 bc	2.84 a	2.54 ab	4.67 ab	4.60 ab
120	10.33 ab	11.00 a	78.00 ab	73.33 bc	12.00 bc	13.00 ab	39.33 ab	36.67 bc	2.75 a	2.68 ab	4.59 ab	4.72 a
LSD	1.65		3.64		1.74		3.64		0.29		0.75	

Table 4: Ionic concentration (%) in DSR Straw as influenced by P application and CR incorporation in saline-sodic soil

P_2O_5 (kg ha^{-1})	P (%)		K (%)		Na (%)		Ca (%)		Mg (%)	
	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR	+ CR	– CR
					2011					
0	0.112 d	0.087 d	1.487 e	1.367 e	0.505 b	0.571 a	0.152 e	0.131 e	0.342 a	0.216 c
40	0.200 c	0.182 c	2.747 cd	2.443 d	0.377 c	0.505 b	0.307 b	0.214 d	0.346 a	0.319 b
80	0.269 a	0.233 b	3.885 a	2.830 bc	0.212 e	0.464 b	0.352 a	0.262 c	0.355 a	0.318 b
120	0.254 ab	0.279 a	3.149 b	2.789 bcd	0.352 cd	0.283 de	0.341 a	0.293 b	0.354 a	0.323 b
LSD	0.026		0.353		0.050		0.026		0.016	
					2012					
0	0.115 e	0.048 f	1.561 c	1.207 c	0.606 a	0.670 a	0.164 e	0.121 f	0.355	0.371
40	0.236 b	0.149 d	2.871 ab	2.287 b	0.356 cd	0.492 b	0.317 b	0.200 d	0.323	0.355
80	0.285 a	0.188 c	3.227 a	2.772 ab	0.305 d	0.439 bc	0.375 a	0.262 c	0.308	0.341
120	0.265 ab	0.177 cd	3.065 a	2.932 a	0.343 cd	0.315 d	0.335 b	0.303 b	0.242	0.361
LSD	0.032		0.459		0.083		0.035		NS	

Means followed by same letter(s) do not differ significantly at $P \leq 0.05$ NS = Non-significant

especially of P grown under salt-affected soils because most of the applied P get fixed and plants cannot fulfill their requirements (Aslam *et al*., 2008; Mahmood *et al*, 2013). In our study, when P was applied without CR incorporation, higher paddy yield was obtained with increasing P rate to 120 kg P_2O_5 ha^{-1} but was significantly less (13%) than 80 kg P_2O_5 ha^{-1} with CR incorporation. The reason might be comparatively high plant population under DSR which requires more nutrition to achieve the potential yield (Byous *et al.,* 2004; Mishra *et al.,* 2005; Sainio *et al*., 2006). On average of two years, the percent increase in paddy over control was 15% with 80 kg P_2O_5 ha^{-1} and CR incorporation. Continuous two year CR incorporation further increased 4% paddy yield during the following year of crop harvest with the same (80 kg P_2O_5 ha^{-1} + CR) treatment. Crop residue incorporation might contributed to growth and paddy yield of DSR planted in saline-sodic soil which upon decomposition substantially changed the nutrient balance and reduced the adverse effect of salinity/sodicity (Ali *et al.,* 2012; Mahmood *et al.,* 2013). This was probably due to the release of carbon that increased partial pressure of CO_2 and thus formation of HCO_3 which enhanced the mitigating effect against salinity/sodicity and increased solubility of added P for plant uptake resulting in better growth and yield. Generally, the rice crop requires more P at early growth stage for stronger root and shoots development and thus boosts up paddy yield (Danga and Wakindiki, 2009; Mahmood *et al*., 2013). The growth and yield increase due to CR incorporation (Eagle *et al.,* 2000; Slaton *et al.,* 2002; Sharma and Prasad, 2003; Krishna *et al.*, 2004) as well as P application (Aslam *et al.*, 2008) have also been documented. Further, CR incorporation might have increased soil microbial activities that enhanced CR decomposition and availability of released nutrients for healthy plant growth (Ali *et al.*, 2012). Microorganisms form symbiotic associations with plant roots that increased the surface area of roots and their access to P. Some microorganisms discharge acids into the soil, which can help to solubilize little P minerals. Increased nutrients in rhizosphere and their rapid availability to growing plants upon complete disintegration of added CR provided favorable environment for healthy root system of growing crops and thus improved their yields. Haq *et al*. (2001), Rath *et al*. (2005), Danga and Wakindiki (2009) and Mahmood *et al*. (2013) reported that CR incorporation increase nutrients availability in soil and plants with well developed roots explore more soil volume for better crop stand.

Growth and yield of wheat were also enhanced with 80 kg P_2O_5 ha^{-1} applied along with CR incorporation and it was the maximum with 120 kg P_2O_5 ha^{-1} without CR incorporation. The incorporation of crop residues enhances fertility status of the soil due to decomposition of added CR and released nutrients status in the soil and providing healthy environment for vigorous plant growth that ultimately caused higher grain yield under saline-sodic conditions. The possible reason of higher yields and higher P uptake (Fig. 1) with CR incorporation might be due to release of native P as a result of acids produced during decomposition as well as chelating effect of organic complexes with P (Haq *et al.*, 2001; Rath *et al.*, 2005; Shiva *et al.*, 2012). Crop residue incorporation appreciably contributed to growth and yield of wheat grown after DSR. Residual P released from fully decomposed CR incorporated during preceding DSR growing season also contributed to a large extent in producing the maximum grain yield of wheat. Further, the longer root system in wheat crop might have absorbed nutrients from deeper soil layers to ensure healthy crop growth and yield. Thus, a higher P application rate (120 kg P_2O_5 ha^{-1}) led to more availability of phosphorus, by enriching P content in the deeper layers where longer roots are more likely to absorb that residual P, thus allowing P uptake to produce maximum yield (Van der Eijk *et al*., 2006). Advantages of rice/wheat residue incorporation in soil and integrated nutrient management has been widely discussed by Byous *et al*. (2004), Mishra *et al*. (2005), Danga and Wakindiki (2009) and Ali *et al.* (2012) who reported that a major part of nutrients (NPK) taken up by rice and wheat crops remains in the straw and become available for following crop plants upon decomposition. Thus, a substantial amount of P requirement for crop growth could be met by the incorporation of rice/wheat residue. Adequate P application approach on problem soils within the rice-wheat cropping system have to guarantee high and sustainable food grain production, high net profit and build-up of native soil P in available form. Probna *et al.* (1976), Sharma and Prasad (2003), Kharub *et al*. (2004) and Yadvinder *et al*. (2004) have also reported similar findings.

The Na^+ concentration in plant tissues was significantly reduced due to CR incorporation and P application and the concentration of P, K^+ and Ca^{2+} was improved. This might be due to enhanced fertility status of the soil due to decomposition of added CR and nutrient release in the soil which resulted in less Na^+, more P, K^+ and Ca^{2+} contents in plant tissues. Ali *et al*. (2001) reported that in the presence of relatively higher nutrients concentration in rhizosphere, plants absorbed and translocated relatively more K^+ and less Na^+ than at lower concentrations. The data indicates that P application even at lower rate along with CR incorporation performed statistically equal to higher dose of P without CR incorporation. Kinraide (1998, 1999); Haq *et al*. (2001) and Ali *et al*. (2003) reported that the root medium salinity interfere with the absorption and translocation of K^+ and Ca^{2+} by plants.

It is reported that enhanced CO_2 partial pressure in the rhizosphere during CR decomposition process and microbial respiration increased the availability of released and added P as well as other essential nutrients. Improved soil physical conditions further contributed to more P uptake and ultimately increased crop growth and yields. Under CR incorporation, additional P application (120 kg P_2O_5 ha^{-1}) did not showed significant difference in P uptake by DSR and wheat crops. This was most probably due to either i) excess Na^+ in root medium that promoted the formation of soluble Na^+ phosphate compounds. Uptake of these compounds by plants caused detrimental effects on plant growth resulting in reduced yields (Table 2) due to which less P uptake was observed or ii) a reduced amount of P availability in rhizosphere due to its fixation might have caused less P uptake. Ali *et al*. (2001) have reported that in the presence of relatively higher nutrient concentration in rhizosphere, plants absorbed and translocated relatively more K^+ and less Na^+ than at lower concentrations.

Conclusion

The application of P @ 80 kg P_2O_5 ha^{-1} even at lower rate (40 kg P_2O_5 ha^{-1}) along with CR incorporation (2 t ha^{-1}) produced maximum DSR paddy and wheat grain yields under saline sodic soil, which was significantly at par with elevated P rate (120 kg P_2O_5 ha^{-1}) without CR incorporation.

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