

Rehabilitation of Salt-Affected Soil Through Residues Incorporation and Its Impact on Growth and Yield of Direct Seeded Rice and Wheat

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Abstract

A two year field study was conducted on a permanent layout to investigate the effect of crop residues (CR) incorporation and P application (0, 40, 80, 120kg P₂O₅ ha⁻¹) on rehabilitation of saline soil (EC_e=4.59 dS m⁻¹; pH=8.38; CaCO₃=3.21%; Extractable P=4.07mg kg⁻¹; sandy clay loam) during 2011-12. The experiment was laid out according to split plot design with three replications. Planting of direct seeded rice (DSR) with and without crop residue incorporation @2ton ha⁻¹ were placed in main plots and P application was in sub plots. Data on productive tillers, panicle length, paddy/grain and straw yields was collected. Soil was sampled (0-15cm) before initiation and after the harvest of last crop. On an average of two years, maximum productive tillers (18), panicle length (33), paddy yield (3.26t ha⁻¹) and was produced with P application @ 80kg P₂O₅ ha⁻¹ along with CR incorporation. Similarly in case of wheat grown after DSR, maximum tillers (17), spike length (17), grain panicle⁻¹ (66) and grain yield (3.56t ha⁻¹) were produced with P application @80kg P₂O₅ ha⁻¹ along with CR incorporation. Although, the growth and yield contributing parameters with this treatment (80kg P₂O₅ ha⁻¹+CR) performed statistically equal to 120kg P₂O₅ ha⁻¹ without CR incorporation during both the years, but on an average of two years, grain yield of DSR and wheat was significantly superior (22 and 24% respectively) than that of higher P rate (120kg ha⁻¹) without CR. Overall, continuous two year CR incorporation further increased (17%) paddy yields during the follow up year of crop harvest. Higher concentration of P, K and Ca²⁺ in both DSR and wheat plant tissues was found where 80kg P₂O₅ ha⁻¹ was applied along with CR incorporation or 120kg P₂O₅ ha⁻¹ alone while Na⁺ and Mg²⁺ concentration decreased with CR incorporation and increasing P rate. The soil salinity was decreased and fertility was improved significantly after two years of study.

Keywords: Slightly saline soil; Direct seeded rice; Crop residues incorporation; P application; Growth and yield; Ionic concentration; P use efficiency

Abbreviations: CR: Crop Residues; EC_e: Electrical Conductivity of Extract; pH; Negative log of Hydrogen Ion; CaCO₃: Calcium Carbonate; P: Phosphorus; mg kg⁻¹: milligram per kilogram; kg P₂O₅ ha⁻¹: Kilogram Phosphate per hectare; DSR: Direct Seeded Rice; cm: Centimeter; t ha⁻¹: ton per hectare; K: Potash; Na⁺ and Mg²⁺: Sodium and Magnesium; PUE: Phosphorus Use Efficiency; SOP: Sulfate of Potash; SAR: Sodium Adsorption Ratio; SOM: Soil Organic Matter; TPU: Total P Uptake; LSD: Least Significant Difference; CO₂: Carbon di Oxide

Introduction

Soil salinity is a major problem in boosting up agricultural production throughout the world due to which million hectares of agricultural land is unable to produce potential crop yields. In regions such as Pakistan, over a quarter of the cultivatable land is occupied by medium to high salinity [1,2]. The problem is going faster because of heavy irrigations with brackish water which further decline the fertility of culturable lands and crop yields [2-6]. Saline soils contain surplus soluble salts (Cl⁻ and SO₄²⁻ of Na⁺, Ca²⁺ and Mg²⁺) which cause high osmotic pressure and compound interactions of Na, Ca and K [7]. These salts disturb the equilibrium in rhizosphere and lessen crop productivity by accumulating hazardous ions. Adequate plant nutrition may reduce ill effects of these ions thereby helping plants to improve their growth under such situations [8-11]. Phosphorus availability in problem soils

is affected by anion competition (PO_4^{3-} and Cl^-) and many other interactions. Applied P is captured by Ca^{2+} present in calcareous soils and reacts with P to form insoluble dibasic Ca^{2+} phosphate compounds and is thus fixed. Much work has been reported regarding nutrient management for conventional crops to enhance their yields under unfavorable situation but much less exertion is reported on direct seeded rice under saline soils. There is a thirst to find out the economical application of nutrients especially of P and its availability to crop plants. Optimized P nutrition is critical for producing potential yields because it encourages healthy growth, development of strong root system, maximum tillering, uphold more flowering and seed formation [12].

Often, P deficiency in rice is referred to as "hidden hunger" which causes poor tillering, slow leaf canopy expansion, poor grain formation and delayed maturity. In our country, more than 90% soils are deficient in P [13]. There are so many factors responsible for low paddy yield production. Farming community in rice-wheat cropping system is facing water shortage, escalating fuel and high fertilizer cost (particularly of P fertilizers) and labour shortage during rice transplanting. About half of the rice cultivated area (~1.0mha) is salt-affected which has moderate to high salinity, high pH and shortage of good quality ground water causing 30-70% paddy yield reduction [14]. Moreover, P availability in soluble orthophosphate form is a prevalent limitation under calcareous soils because it makes insoluble compounds and does not release plant available P even upon heavy irrigations. Although, a large proportion of applied P in the soil becomes immobile due to this process [11,15]. However, the plants readily utilize only 8-33% of applied P in the first growing season [16]. Hence, there is a need to increase the use of P fertilizers in order to guarantee food security for ever increasing populations. Soils containing insufficient amounts of plant-available P not only produce economically deplorable yields, but other inputs are also used less efficiently. Thus, there is an urgent need to seek out strategies by which P fertilizers can be used more effectively in such farming systems where P is deficient and where its use is economically practicable. Most of the farmers of rice-wheat cropping system burn wheat crop residues to prepare their lands for timely rice transplanting. This practice not only despoil the environment but also the precious source of plant nutrients, main source of organic material and the important constituent for soil health are being smashed on large scale in this 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 [11,17]. In many studies, recycling of crop residues is reported to increase the organic carbon, nutrient contents, increased crop yields [18-20].

Direct seeding of rice is a new and the most suitable technology for resource poor community of salt-affected lands for which transplanting labour cost, water and machinery tools expenses required during puddling and transplanting could be saved in

addition to timely sowing of rice. The crop matures early as compared to traditional transplanting which further makes possible sowing of wheat crop well in time after the harvest of rice. Besides these benefits, there is much more plant population under direct seeded rice as compared to traditionally transplanted rice for which nutrients requirement could also be higher to produce potential yields. A little work is reported regarding nutrient management particularly of P application for direct seeded rice in salt-affected soils of Pakistan. Therefore, keeping all these factors in mind, a long-term field study was planned to investigate appropriate P dose for direct seeded rice along with wheat straw incorporating and their impact on paddy yield in a slightly saline soil of district Hafizabad.

Materials and Methods

A two year study under a permanent layout was conducted in marginal saline soil of rice-wheat cropping system at farmers field in district Hafizabad of Pakistan having $\text{EC}_e = 4.59 \text{ dS m}^{-1}$, $\text{pH} = 8.38$, $\text{SAR} = 6.57 (\text{mmol}_c \text{ L}^{-1})^{1/2}$, Extractable P = 4.07 mg kg^{-1} , $\text{CaCO}_3 = 3.21\%$, and sandy clay loam texture during 2011 and 2012 (Table 1-5). The experiment was laid out according to split plot design with three replications. Planting methods i.e., direct seeding with and without crop residue (wheat) incorporation @ 2 t ha^{-1} were kept in main plots and various P doses (0, 40, 80 and $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) were applied in sub plots. Recommended basal dose of N @ 100 kg ha^{-1} (half at sowing time and remaining half at tillering stage) and K @ 50 kg ha^{-1} as SOP were applied to all the plots at the time of sowing. Soaked seed (for 24) of rice cv. Supper-2000 @ 40 kg ha^{-1} was broadcasted uniformly. The same inputs were applied to intermediate wheat crop. Effective weedicides were used to control weeds and the crop was grown to maturity. All agronomic requirements and plant protection measures were met throughout the growth period whenever required. Pre-sowing and after the harvest final crop soil samples (0-15cm depth) were collected for EC_e , SAR, pH, Soil Organic Matter (SOM), P, K Ca contents analysis (Table 6 & 7) according to the methods suggested by Ryan et al. [21]. Plant samples were collected at maturity for the determination of ionic concentration in tissues. Dried and ground samples were digested in perchloric-nitric acid (2:1 1N) mixture [22] to estimate P, K, Na^+ , Ca^{2+} and Mg^{2+} concentration in plant tissues by spectronic-20 and atomic absorption spectrophotometer. At maturity, the crop was harvested and agronomic data on fertile tillers, plant height, panicle length, grains panicle⁻¹, 1000-grain weight, paddy and straw yields were recorded. Phosphorus use efficiency (PUE) was computed by using the following formula as suggested by Fageria et al. [23]

$$\text{PUE} (\%) = \frac{(\text{TPU}_F) - (\text{TPU}_C)}{\text{Pdose} (\text{kg ha}^{-1})} \times 100$$

Where TPU_F is Total P uptake (kg ha^{-1}) in Fertilized Plots and TPU_C is Total P uptake (kg ha^{-1}) in Control Plots. Total PU was calculated as:

$$\text{TPU} (\text{kg ha}^{-1}) = \frac{\text{P contents} (\%) \text{ in plant party (dry matter)} \times \text{Yield} (\text{kg ha}^{-1})}{100}$$

Table 1: Growth and yield of direct seeded rice influenced by P application and CR incorporation under saline soil (Average of three repeats).

P ₂ O ₅ (kg ha ⁻¹)	Tillers		Plant Height (cm)		Panicle Length (cm)		Grain Panicle ⁻¹		Paddy Yield (t ha ⁻¹)		Straw Yield (t ha ⁻¹)	
	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR
2011												
0	13.67 bc	8.00 d	126.33 a	118.00 b	26.00 bc	17.67 d	108.67 bc	78.33 d	2.497 cd	1.887 e	6.430 ab	4.760 c
40	14.00 bc	12.33 c	129.00 a	119.67 b	27.00 bc	22.00 c	110.67 b	99.33 c	2.637 bc	2.215 d	6.590 a	5.657 b
80	17.67 a	15.67 ab	130.00 a	120.67 b	30.67 a	24.67 bc	119.33 a	105.67 bc	2.987 a	2.707 abc	6.980 a	6.523 ab
120	16.00 ab	16.00 ab	130.00 a	120.67 b	28.00 ab	27.00 ab	115.67 a	114.33 ab	2.852 ab	2.817 abc	6.830 a	6.737 a
LSD	2.8362		4.6787		3.1727		8.36		0.2639		0.9532	
2012												
0	14.67 bc	9.33 d	125.67 b	98.00 d	29.33 bc	17.00 e	105.67 de	86.00 f	2.873 bc	1.560 e	7.223 b	5.090 d
40	15.00 bc	13.00 c	127.00 ab	114.00 c	31.00 b	24.00 d	113.33 bc	99.00 e	3.103 abc	2.127 d	7.313 b	5.750 c
80	18.67 a	15.67 ab	133.67 a	115.33 c	35.67 a	25.33 cd	122.67 a	109.00 cd	3.537 a	2.723 c	7.913 a	6.542 b
120	16.33 ab	16.33 ab	129.00 ab	116.33 c	31.67 b	26.67 bcd	118.67 ab	115.00 ab	3.308 ab	3.307 ab	7.510 ab	6.730 b
LSD	2.4983		7.794		3.7621		5.6257		0.5246		0.5817	

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

Table 2: Growth and yield of wheat influenced by P application and CR incorporation under saline soil (Average of three repeats).

P ₂ O ₅ (kg ha ⁻¹)	Tillers		Plant Height (cm)		Spike Length ⁻¹ (cm)		Grain Spike ⁻¹		Grain Yield (t ha ⁻¹)		Straw Yield (t ha ⁻¹)	
	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR
0	9.33 d	6.67 e	81.00 ab	71.00 b	12.67 cd	9.67 e	33.00 c	20.67 d	2.652 c	1.591 e	5.936 ab	3.476 d
40	12.33 c	8.67 de	88.33 a	74.33 b	14.33 bc	11.00 de	46.67 b	42.67 b	3.194 abc	2.054 d	6.314 ab	4.433 c
80	17.00 a	14.00 bc	89.67 a	78.67 ab	17.33 a	12.67 cd	56.33 a	43.67 b	3.560 a	2.877 bc	6.676 a	5.447 b
120	14.33 bc	16.33 ab	89.33 a	79.00 ab	15.33 ab	16.33 ab	48.33 b	46.00 b	3.259 ab	3.320 ab	6.377 ab	6.547 a
LSD	2.4807		9.2534		2.5848		6.2967		0.42		0.9954	

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

Table 3: Ionic concentration (%) in DSR straw affected by P application and CR incorporation under saline soil (Average of three repeats).

P ₂ O ₅ (kg ha ⁻¹)	K		Na		Ca		Mg	
	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR
2011								
0	1.906 e	1.827 e	0.276 bc	0.459 a	0.196 c	0.091 d	0.196 b	0.389 a
40	2.268 de	2.167 de	0.266 bc	0.315 b	0.234 c	0.212 c	0.195 b	0.374 a
80	3.445 a	2.555 cd	0.144 e	0.230 cd	0.322 a	0.247 bc	0.141 b	0.390 a
120	2.920 b	2.992 b	0.178 de	0.209 cde	0.298 ab	0.320 a	0.135 b	0.355 a
LSD	0.4237		0.0473		0.0618		0.0738	

2012								
0	2.016 de	1.666 e	0.225 bc	0.419 a	0.126 d	0.085 e	0.120 c	0.215 a
40	2.748 bc	2.044 de	0.178 cd	0.290 ab	0.197 c	0.116 de	0.115 cd	0.174 b
80	3.645 a	2.289 cd	0.138 d	0.228 bc	0.291 a	0.196 c	0.094 d	0.143 c
120	3.053 b	2.739 bc	0.184 cd	0.199 cd	0.249 b	0.276 ab	0.107 d	0.106 d
LSD	0.4977		0.0734		0.0331		0.0275	

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

Table 4: Ionic concentration (%) in DSR paddy influenced by P application and crop residues (CR) incorporation under saline soil (Average of three repeats)

P ₂ O ₅ (kg ha ⁻¹)	K		Na		Ca		Mg	
	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR
	2011							
0	0.790 f	0.264 g	0.127 bc	0.241 a	0.142 c	0.077 d	0.134 b	0.196 a
40	1.310 de	1.032 ef	0.116 bc	0.171 b	0.194 b	0.156 bc	0.106 cd	0.189 a
80	1.853 a	1.385 cd	0.087 c	0.137 bc	0.298 a	0.188 bc	0.079 e	0.183 a
120	1.570 bc	1.658 ab	0.098 c	0.104 c	0.272 a	0.251 a	0.098 de	0.123 bc
LSD	0.2035		0.0473		0.0327		0.0213	
2012								
0	0.835 d	0.282 e	0.149 bc	0.212 a	0.165 cd	0.045 e	0.112 cd	0.235 a
40	1.325 bc	1.136 c	0.096 d	0.159 b	0.226 b	0.154 d	0.099 cde	0.177 b
80	1.854 a	1.391 b	0.063 e	0.117 cd	0.291 a	0.192 bc	0.044 e	0.129 bc
120	1.674 a	1.759 a	0.085 de	0.089 de	0.265 a	0.219 b	0.068 de	0.063 de
LSD	0.1875		0.032		0.0358		0.0567	

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

Table 5: Ionic concentration (%) in wheat plant tissues influenced by P application and crop residues (CR) incorporation under saline soil (Average of three repeats).

P ₂ O ₅ (kg ha ⁻¹)	K		Na		Ca		Mg	
	+ CR	- CR	+ CR	- CR	+ CR	- CR	+ CR	- CR
	Straw							
0	1.249 c	1.163 c	0.136 bc	0.221 a	0.124 d	0.105 d	0.143 bc	0.216 a
40	1.896 ab	1.148 c	0.104 de	0.207 a	0.211 b	0.177 c	0.135 bcd	0.198 a
80	2.100 a	1.800 b	0.089 e	0.169 b	0.293 a	0.205 bc	0.106 cd	0.149 b
120	1.923 ab	1.874 ab	0.097 e	0.135 cd	0.219 b	0.222 b	0.121 bcd	0.102 d
LSD	0.2321		0.031		0.0329		0.0403	
Grain								
0	0.992 d	0.532 e	0.192 ab	0.207 a	0.124 bc	0.059 d	0.177 a	0.194 a
40	1.180 cd	0.994 d	0.144 c	0.174 b	0.173 b	0.108 c	0.118 bc	0.168 a
80	1.738 a	1.356 bc	0.098 f	0.138 cd	0.253 a	0.139 bc	0.076 d	0.137 b
120	1.517 ab	1.575 ab	0.116 de	0.110 ef	0.180 b	0.181 b	0.094 cd	0.106 cd
LSD	0.2484		0.017		0.0472		0.0271	

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

The data thus, 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 [24].

Results

Growth and yield of DSR

On an average of two years data, maximum fertile tillers (19), panicle length (34cm), grain panicle⁻¹ (121) and paddy yield (3.26t ha⁻¹) were produced with P application @ 80kg P₂O₅ ha⁻¹ along with CR incorporation during first and second cropping years, respectively (Table 2). Although, these parameters were statistically at par with P application @ 120kg P₂O₅ ha⁻¹ without CR incorporation during both the years but grain yield harvested with P application @ 80kg P₂O₅ ha⁻¹ along with CR incorporation was significantly superior when compared with higher P rate (120kg ha⁻¹) without CR during both the cropping years. On an average of two-year data, paddy produced by this treatment showed 22% additional yield over control (0kg P ha⁻¹+CR). Under CR incorporation, further increase in P application (120kg P₂O₅ ha⁻¹) caused 6% paddy yield reduction as compared to the P application @ 80kg P₂O₅ ha⁻¹. During second cropping year, interestingly the lower dose of P (40kg P₂O₅ ha⁻¹+CR) performed reasonably better but was slightly comparable with higher rate of P (120kg P₂O₅ ha⁻¹) without CR incorporation. Overall, continuous two-year CR incorporation further increased 17% paddy yield during the follow up year of crop harvest as compared to previous crop harvest under CR incorporation.

Growth and yield of wheat crop

Although, under CR incorporation, minimum number of productive tillers (9.33), spike length (12.67cm), grain spike⁻¹ (33.00) and grain yield (2.87t ha⁻¹) were produced from the plots where no P was applied but these parameter were significantly higher than that of control treatment (0kg P₂O₅ ha⁻¹) without CR incorporation (Table 3). A considerable increase in growth and yield components, straw and grain yields of wheat grown were

observed with P fertilization and CR incorporation. Maximum fertile tillers (17), spike length (17cm), grain panicle⁻¹ (56) and grain yield (3.56t ha⁻¹) was produced with P application @ 80kg P₂O₅ ha⁻¹ along with CR incorporation, which was obviously superior (7%) than the higher P application (120kg P₂O₅ ha⁻¹) rate without CR incorporation. After the harvest of first DSR crop, the wheat grain yield harvested with P application under CR incorporation even in lesser amount (40kg P₂O₅ ha⁻¹) performed slightly equal to higher P rate (120kg P₂O₅ ha⁻¹) without CR incorporation. When P was applied without CR incorporation, maximum grain yield was obtained with increasing the rate of P and was the highest where P was applied @ 120kg P₂O₅ ha⁻¹ but was not as much as harvested with 80kg P₂O₅ ha⁻¹ under CR incorporation.

Ionic concentration and PUE of DSR and Wheat

It is evident from the data in Table 4 & 5 that high Na⁺ and Mg²⁺ while low K⁺ and Ca²⁺ concentrations were determined from both DSR and wheat plant tissues where no P was applied without CR incorporation. Phosphorus application and CR incorporation significantly reduced saline ions (Na⁺ and Mg²⁺) concentration and improved K⁺ and Ca²⁺ in both DSR and wheat crop plants. The data indicated that P application particularly with CR incorporation considerably decreased Na⁺ concentration and increased K⁺ and Ca²⁺ concentration in plant tissues. Phosphorus application still at lower rate (40kg P₂O₅ ha⁻¹) along with CR incorporation performed better or even statistically equal to higher dose of P (120kg P₂O₅ ha⁻¹) without CR incorporation. Similarly, maximum PUE in case of DSR (26%) and wheat (23%) was reflected from the plots treated with 80kg P₂O₅ ha⁻¹ application under CR incorporation (Figure 1) which was comparable with higher P dose (120kg P₂O₅ ha⁻¹) under no CR incorporation. Under CR incorporation, further increase in P application (120kg P₂O₅ ha⁻¹) did not showed significant difference in PUE by both the crops. On the other hand, when P was applied without CR incorporation, maximum PUE was determined from the treatments where P was applied at higher rate (120kg P₂O₅ ha⁻¹) and was not as much of P application @80kg P₂O₅ ha⁻¹ under CR incorporation.

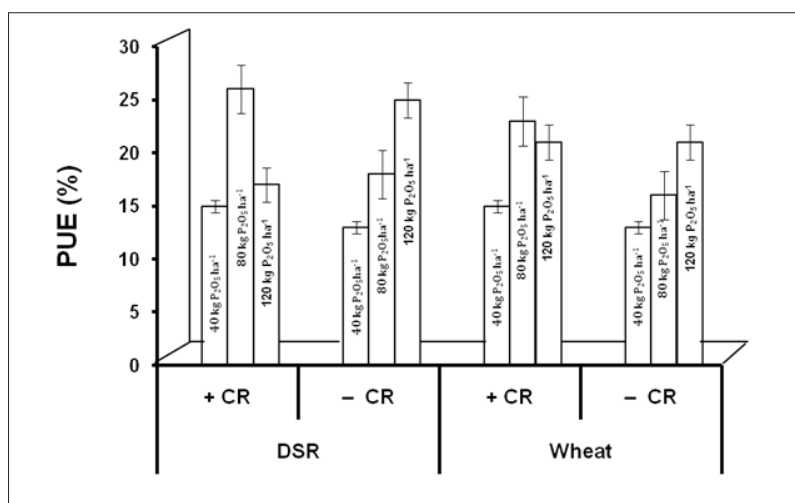


Figure 1: PUE (%) of DSR and Wheat as influenced by CR incorporation and P application under saline soil.

Effect of CR on soil physical status E_c, SAR and pH

After the harvest of final DSR crop, overall 21% decline in E_c with CR incorporation was observed as compared to before the sowing of DSR with CR incorporation (Table 6). Increasing the rate of P application under CR incorporation also caused a significant reduction in E_c being the maximum decline with higher rates of P₂O₅ (80 and 120kg ha⁻¹) after completion of study. The E_c fell down to 3.79dS m⁻¹ against 4.15dS m⁻¹ before sowing of DSR due

to CR incorporation and was exactly below the acceptable limit of soil E_c for successful crop growth and yield production. Similarly, under CR incorporation, there was also a considerable reduction in the value of SAR from 6.57 before crop sowing to 4.87 (mmol_c L⁻¹)^{1/2} after the harvest of third season DSR crop. A minimum mean value of pH (8.15) was observed from the plots incorporated with CR. Decrease in pH value under CR incorporation along with P application was slightly higher as compared to control (0kg P₂O₅ ha⁻¹) plots.

Table 6: Physico-chemical analysis of saline soil before initiation and after the study during 2011-12 (Average of 3 repeats).

	E _c			SAR			pH		
	+ CR	- CR	Mean	+ CR	- CR	Mean	+ CR	- CR	Mean
Before Sowing									
0	4.59 ^{NS}	4.58 ^{NS}	4.58 ^{NS}	6.57 ^{NS}	6.56	6.57 ^{NS}	8.38 NS	8.38 ^{NS}	8.38 ^{NS}
40	4.57	4.57	4.58	6.56	6.57	6.57	8.39	8.37	8.38
80	4.58	4.59	4.58	6.57	6.56	6.57	8.38	8.38	8.38
120	4.58	4.58	4.58	6.56	6.57	6.57	8.38	8.39	8.38
Mean	4.58 NS	4.58		6.57NS	6.57		8.38 NS	8.38	
After the Harvest of final Crop									
0	3.87 d	4.58 a	4.22 A	4.92 d	6.57 a	5.74 A	8.18 c	8.38 a	8.28 A
40	3.84 d	4.51 b	4.17 B	4.87 de	6.45 b	5.66 B	8.16 c	8.37 a	8.27 B
80	3.69 f	4.42 c	4.06 C	4.82 e	6.42 bc	5.62 BC	8.11 e	8.34 b	8.23 C
120	3.77 e	4.38 c	4.08 C	4.85 de	6.36 c	5.61 C	8.14 d	8.32 b	8.23 C
Mean	3.79 B	4.47 A		4.87 B	6.45 A		8.15 B	8.35 A	

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

Soil Organic Matter (SOM) and P, K and Ca contents

The data in Table 7 shows that at the end of study, there was a significant improvement in organic matter content as well as P,

K and Ca availability owing to continuous CR incorporation and P fertilization. Maximum SOM, P, K and Ca contents were recorded with increased P application rate under CR incorporation in saline soil.

Table 7: Organic Matter (OM) and Nutrient Status of saline soil before initiation and after the study during 2011-12 (Average of 3 repeats)

	OM			K			Ca		
	+ CR	- CR	Mean	+ CR	- CR	Mean	+ CR	- CR	Mean
Before Sowing									
0	0.52 ^{NS}	0.54 ^{NS}	0.54 ^{NS}	78.03 ^{NS}	77.05 ^{NS}	77.02 ^{NS}	42.11 ^{NS}	43.04 ^{NS}	42.29 ^{NS}
40	0.54	0.52	0.54	77.1	76.49	77.02	43.24	41.22	42.29
80	0.53	0.54	0.54	79.09	77.02	77.02	42.73	41.57	42.29
120	0.54	0.53	0.54	76.62	77	77.02	41.58	43.86	42.29
Mean	0.54	0.54		77.02NS	77.02		42.29NS	42.29	
After the Harvest of final Crop									
0	0.68 ^{NS}	0.49 ^{NS}	0.59 ^{NS}	95.26 a	78.86 d	87.06 A	49.20 a	33.79 c	41.50 A
40	0.69	0.52	0.61	93.46 b	75.73 e	84.60 B	48.55 ab	32.79 d	40.67 B
80	0.71	0.53	0.62	88.48 c	73.86 e	81.17 C	48.13 b	32.67 d	40.40 B
120	0.7	0.54	0.62	91.75 b	70.82 f	81.29 C	48.33 b	32.76 d	40.55 B
Mean	0.69 A	0.52 B		92.24 A	74.82 B		48.55 A	33.00 B	

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

Discussion

Growth and yield of DSR and Wheat

Crop residue incorporation positively contributed in growth and yield of DSR particularly during second year. This was most probably due to complete decomposition and mineralization of added CR that enriched the soil with mineral nutrients in addition to improvement in soil physical condition by ameliorating toxic effects of hazardous ions. Moreover, water and P retention capacity might have also been improved due to added CR that retained comparatively excess moisture and P availability for a longer time. Besides, fabrication of acid farming substances by microbial activities and partial pressure of CO₂ released during CR decomposition decreased soil pH and enhanced P availability and other necessary plant nutrients which encouraged healthy plant growth and hence yields. Crop residue incorporation upon decomposition substantially altered the nutrient stability in soils and reduced the adverse effect of saline ions. Similar points of view have also been documented by [11,25-27]. Further, adequate P fertilization promoted vigorous early plant growth, improved tillering and increased number of grains per panicle which eventually produced better yield of DSR [12,28].

The increase in yield due to CR incorporation as well as P application have also been well documented by Eagle et al. [19], Slaton et al. [29], Sharma and Prasad [30], Krishna et al. [20], Aslam et al. [10], Ali et al. [31]. A significant increase in growth and yield components, straw and grain yields of wheat grown after DSR was observed with P fertilization and CR incorporation. This was definitely attributable to CR incorporation that reduced the intake of saline ions (Table 5) and enhanced PUE (Figure I). Besides, adequate P application and its judicious utilization further facilitated to improve growth and yield contributing parameters. As it have been discussed earlier, that CR incorporation upon decomposition substantially changed the nutrient balance in rhizosphere and microorganisms form symbiotic associations with plant roots increase the surface area and their access to P. Some microorganisms discharge acids into the soil which can help to solubilize little P minerals. Conversely, minimum number of productive tillers, panicle and spike lengths, DSR grains panicle⁻¹, wheat grains spike⁻¹ and yields in case of control (0kg P₂O₅ ha⁻¹) of both DSR and wheat crops were due to the P deficiency that directly distorted the normal tillering and grain formation by inhibiting their materialization and hence reduced yields [32,33]. When P was applied without CR incorporation, higher grain yield was obtained with increasing P rate and was the maximum where P was applied @120kg P₂O₅ ha⁻¹. Better crop growth and yield with maximum P application (120kg P₂O₅ ha⁻¹) under no CR incorporation could be due the reason that crops grown under salt-affected soils demands relatively higher nutrition to reach the potential yields [8,10]. But again this yield (harvested with 120kg P₂O₅ ha⁻¹) under no CR incorporation was, however, 6% less than obtained from 80kg P₂O₅ ha⁻¹ with CR incorporation. It is obvious from the data in Table 3 that during second year of crop grown under CR incorporation, even lower P rate (40kg P₂O₅ ha⁻¹) performed moderately as equal to higher rate (120kg P₂O₅ ha⁻¹ with no CR) for both the crops. This

happened most probably due to native P release from fixed sites due to acidified rhizosphere as a result of microbial activities during CR decomposition that enhanced its availability and ultimately grain yields. Moreover, fully decomposed CR and mineralization during subsequent wheat and DSR growing season presumably enriched the soil with mineral nutrients that contributed to a large extent in producing the maximum grain yields. Further, the longer root system in wheat crop might have absorbed nutrients from deeper soil layers to ensure healthy crop growth and hence yield. Thus, a higher application rate led to more P availability by enriching P content in the deeper layers where longer roots absorbed that residual P, consequently allowing more P uptake to produce maximum yield.

There are several reports that signify the role of P application in the enhancement of crop yields [27,32,34]. Advantages of crop residue incorporation in soil and integrated nutrient management has been widely discussed by Byous et al. [17], Shiva et al. [35] and Ali et al. [31] 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. Similar conclusions have also been reported by Abid et al. [36], Sharma & Prasad [30], Kharub et al. [37] and Yadvinder et al. [38]. Consequently, a substantial amount of P requirement for crop growth could be met by the incorporation of CR. 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.

Ionic concentration in plant tissues, PUE and soil physical status

The higher concentrations of P, K⁺ and Ca²⁺ in CR treated plots could be due to enhanced mineral nutrition in soil through complete decomposition and mineralization of incorporated CR, which improved the nutrient status in the plough layer and P application further facilitated their intake by crop plants because of synergistic effect with saline ions [11,29]. Phosphorus application particularly with CR incorporation considerably decreased Na⁺ contents and increased K⁺ and Ca²⁺ concentrations in plant tissues. Ali et al. [39] have 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 indicated that P application still at lower rate (40kg P₂O₅ ha⁻¹) along with CR incorporation performed better or even statistically equal to higher dose of P without CR incorporation. These findings could also be supported by the results of Kinraide [40,41], Haq et al. [42], Delgado et al. [32] and Mahmood et al. [43] who reported that the root medium salinity interferes with the absorption and translocation of K⁺ and Ca²⁺ by plants.

In the earlier discussion, it has been reported that enhanced CO₂ 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. Crop residues incorporation upon decaying certainly modified the environment by adding organic matter and nutrients as well.

This could be supported by the data in Tables 6 & 7. Improved soil physical conditions further contributed to more P uptake and ultimately increased crop growth and yields. Under CR incorporation, additional increase in P application ($120\text{kg P}_2\text{O}_5\text{ ha}^{-1}$) did not showed significant difference in PUE by both the crops. On the other hand, when P was applied without CR incorporation, maximum PUE was determined from the treatments where P was applied at higher rate ($120\text{kg P}_2\text{O}_5\text{ ha}^{-1}$) and was not as much of P application @ $80\text{kg P}_2\text{O}_5\text{ ha}^{-1}$ under CR incorporation. This was most probably due to excessive uptake of saline ions in the form of Na_2PO_4 compounds [11] that comparatively reduced biomass production of both the crops which resulted in relatively less PUE. Further the retention of P in soil in the forms that are not directly available to plants is, fundamentally, an intrinsic soil characteristic. Many studies have investigated the effects of pH variation on P retention and availability, but reliable enhancement in soil P availability has not yet been obtained. However, minor changes may be achievable. For example, evidences from many detailed studies show that the more organic matter there is in soil, the more the amount of very readily-available plant P [31,44-46]. Our results indicated that P application @ $80\text{kg P}_2\text{O}_5\text{ ha}^{-1}$ along with CR incorporation (2t ha^{-1}) was found to be superior than rest of the treatments in terms of producing maximum grain yields of both DSR and wheat crops grown under marginally saline soil [47,48]. During second year of DSR grown under CR incorporation, the lower P application rate ($40\text{kg P}_2\text{O}_5\text{ ha}^{-1}$) performed slightly better and produced comparable paddy yield as that of higher P application rate ($120\text{kg P}_2\text{O}_5\text{ ha}^{-1}$) without CR incorporation. Therefore, continuous CR incorporation is worth recommended to restore soil fertility as well as productivity.

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