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Full Length Article

Phosphorus Availability in Different Salt-affected Soils as Influenced by Crop Residue Incorporation

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Abstract

An incubation study on phosphorus availability in two different naturally salt-affected soils (saline sodic; EC_e = 6.59 dS m^{-1}; pH_s = 8.29; SAR = 17.39 ($mmol_c$ $L^{-1})^{1/2}$; $CaCO_3$ = 3.47%; Extractable P = 2.97 mg kg^{-1}; sandy loam and slightly salt-affected; EC_e = 4.21 dS m^{-1}; pH_s = 8.18; SAR = 6.57 ($mmol_c$ $L^{-1})^{1/2}$; $CaCO_3$ = 3.21%; Extractable P = 2.76 mg kg^{-1}; sandy clay loam) with and without crop residues was conducted at National Agricultural Research Centre, Islamabad during 2011. Completely randomized design (factorial) with three replications was followed. Dried wheat straw (1 g kg^{-1} of soil) was incorporated uniformly in the respective pots. The phosphate fertilizer was added @ 20, 40 and 60 mg P_2O_5 kg^{-1} of soil as commercial TSP after the soils were transferred to the incubation pots of one kilogram capacity. Soil samples were collected periodically (0, 30, 60, 90 and 120 days after incubation) and analyzed for P availability. It was observed that greater P was available at the first day just after P application with and without crop residue (CR) that decreased gradually with the passage of time. After 60 days, the mean available P was 16.61 and 14.18 ppm in treatment T_4 (60 mg P_2O_5 kg^{-1} soil) in saline-sodic soil with and without CR, respectively, while it was 13.21 and 11.75 ppm in marginally saline soil with and without CR, respectively in the same treatment. Although, initially there was no significant difference in P availability with CR incorporation as compared to without CR treatment however, after 60 days of incubation it increased significantly. The study indicated that after 60 days of incubation, both soils were able to maintain 41 and 39% P, respectively in available form when P_2O_5 was applied @ 60 mg kg^{-1} along with CR incorporation that was 11 and 9% higher as compared to the soils having no CR. Overall, the CR incorporation not only improved P availability but also lowered EC_e (2% and 6%) and SAR (5% and 4%) of saline sodic and slightly salt-affected soils, respectively. © 2013 Friends Science Publishers

Keywords: Saline soil; Saline-sodic soil; Wheat crop residues; P availability; EC_e; SAR

Introduction

In cultureable land of Pakistan, 6.68 mha soils are salt-affected out of which 2.67 mha are in the Punjab Province having moderate to high salinity and sodicity (Ghaffor *et al*., 2004; Anonymous, 2011). Phosphorus (P) is an essential macronutrient, being required by plants in relatively large quantity i.e., ~0.2 to 0.8% (Mengel and Kirkby, 1987; Mills and Jones, 1996). The availability of P to plants for uptake and utilization is messed up in alkaline and calcareous soils due to formation of poorly soluble calcium phosphate raw materials and hence fixation and precipitation of applied P. Presence of lime in alkaline soils further exacerbates its availability and in calcareous soils, lime reacts with soil solution P to form strong calcium phosphate compounds. The resulting effect of low P solubility in calcareous alkaline soils is relatively poor P fertilizer efficiency. Plants grown on such soils can be stunted with shortened internodes and poor root system due to P deficiency. The P plays an important role in early vegetative growth stages, because it promotes tillering and root development (Slaton *et al*., 2002; Sainio *et al*., 2006). Simply adding P fertilizer at normal rates in these soils may not result in optimal yield and crop quality (Stark and Westermann, 2003). Most of the crops are highly sensitive to even moderate salinity at germination, early seedling establishment and grain filling stage.

The P deficiency is a well known nutrient constraint on salt-affected soils. However, resource-poor farmers try to overcome the problem by applying phosphatic fertilizers. The expensive phosphatic fertilizers are becoming out of the reach of poor farmers day by day and reserves remaining in the world could be depleted in about 60–80 years (Runge-Metzger, 1995). Besides, P availability in soluble orthophosphate form is an other limitation under calcareous soils because it makes insoluble dibasic calcium phosphate dihydrate ($CaHPO_4.2H_2O$), octacalcium phosphate ($Ca_4H(PO_4)_3.3H_2O$), and hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$. The

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formation of each product reduces P solubility that does not become available even upon flooding. Although, a large proportion of applied P in the soil becomes static due to this process (Rahmatullah *et al*., 1994), 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 decreases 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 even with P fertilization (Chhabra *et al.*, 1982; Mahmood *et al.*, 1994; Qadir, *et al.*, 2003; Ghafoor *et al*., 2004).

Mostly rice is grown after wheat crop in rice-wheat area of northern Punjab. A considerable area under wheat is being harvested by combine harvester which leaves behind a large amount of loose straw in the field. Crop residues are good source of plant nutrients, primary source of organic carbon added to the soil and the important component for soil health and the stability of agricultural ecosystem (Iqbal *et al.*, 2011), but the farmers burn it due to their impenetrability and difficulty in seed bed preparation for the following crop because the operation is time consuming and labor intensive. About 25% of N and P, 50% of the S, and 75% of K uptake by cereal crops are retained in CR, making them valuable nutrient sources. Thus a large portion of plant nutrients taken up by plants remains in the straw, which could be recycled for subsequent crop growth after its decomposition (Byous *et al.*, 2004). In many studies, recycling of CR is reported to increase the organic carbon and nutrient contents; decreased soil bulk density and increased crop yields (Misra *et al*., 1996; Eagle *et al*., 2000). Therefore, any measure through, which the healthy crop stand could be obtained from salt-affected lands, would be a step forward to improve the yields. Keeping all these factors in mind, an incubation study was designed to investigate the applied P status with and without crop residues under two different salt-affected soils.

Materials and Methods

Effect of CR incorporation on P availability in two different marginally salt-affected soils was studied at National Agricultural Research Centre, Islamabad during 2011. The soils were collected from naturally salt-affected fields from two locations in district Hafizabad i.e., Soil-I from Soil Salinity Research Institute (SSRI) Farm, Pindi Bhattian (saline sodic; EC_e = 6.59 dS m^{-1}; pH_s = 8.29; SAR = 17.39 $(mmol_c\ L^{-1})^{1/2}$; $CaCO_3$ = 3.47%; Extractable P = 2.97 mg kg^{-1}) and Soil-II from Farmer's field in Wachhoki, Khankah Dogran-Hafizabad Road (slightly saline soil; EC_e = 4.21 dS m^{-1}; pH_s = 8.18; SAR = 6.57 $(mmol_c\ L^{-1})^{1/2}$; $CaCO_3$ =3.21%; Extractable P = 2.76 mg kg^{-1}). The soils were air-dried after removal of stones, or any included plant parts and were analyzed for basic physico-chemical properties (Table 1). Treatments applied were:

T_1 = Control (No P application)
T_2 = 20 mg P_2O_5 kg^{-1} soil
T_3 = 40 mg P_2O_5 kg^{-1} soil
T_4 = 60 mg P_2O_5 kg^{-1} soil

Air-dried wheat straw was cut into approximately 1–2 cm size that matched the combine harvester left-over in the fields, and 1g kg^{-1} of soil was incorporated uniformly in all pots except control pots. The soils were moistened at their respective water holding capacity by distilled water. Phosphate fertilizer was added @ 20, 40 and 60 mg P_2O_5 kg^{-1} soil as commercial TSP after the soils were transferred to the incubation pots of one kilogram capacity. The pots were arranged randomly following completely randomized design (factorial) with three replications to enhance randomization and reduce error chances. The availability of applied P was studied under incubation condition for 120 days with controlled constant temperature of 25°C and moisture (at field capacity) placed in the dark. Soil samples collected periodically (0, 30, 60, 90 and 120 day) were analyzed for available P according to the methods suggested by Ryan *et al*. (2001). 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 0.1% probability level (Gomez and Gomez, 1984).

Results and Discussion

Transformation in Added P under Saline-sodic Soil

Availability of applied P in saline sodic soil was initially maximum i.e., in the range of 11.57 to 28.10 ppm just after P application @ 20, 40 and 60 mg kg^{-1} soil under CR incorporation. It is evident from Fig. 1a that P availability decreased gradually with the passage of time and was minimum beyond 90 days of incubation but under CR incorporation its availability was significantly higher than the soil with out CR. Crop residues in soil may be able to rapidly sorb applied P fertilizers that reportedly obstructed P fixation as compared to that of the soil without CR after 60 days of incubation period in addition to its release after decomposition. Probably the decrease in P sorption was not related to competition from the decomposition products of CR, but was the result of P release from the CR after 60 days of incubation and its availability was significantly higher than that of the soil having no CR. This might be due to that CR served both as a source of subsurface P and an effective mobilizing agent. Hussain *et al.* (2003) reported that in soils with high P sorption capacities and strong P binding energy, a less soluble P source that releases P to soil solution in smaller concentrations slow down the P fixation reaction in soils and maintain fertilizer P in available form for a long period. Similar results have also been documented by Nash *et al.* (2005) and Ray von Wandruszka1 (2006).

Overall, the decrease in P availability with the passage of time might have been due to its fixation because of the presence of more active sites for P sorption, which in turn, may be attributed to its high alkalinity (pH_s > 8.2) and lime (> 3.4% $CaCO_3$) present in the soil (Table 1). Aslam *et al*. (2000) and Mahmood *et al.* (2000) also reported similar conclusions that P sorption increased with increasing P in equilibrium and was maximum in soils having high $CaCO_3$ contents. When P fertilizer was added to the soil, a small part of it went to the soil and remained available for some time, while the rest was either adsorbed or precipitated. Resembling interpretations have been reported by Ahmad *et al*. (2003) that the available P ranged from 0.3 to 12.6 ppm with an average of 5.89 mg kg^{-1} soil in rice growing area of the Punjab. The results of this study did not corroborate those of Polyzopoulos *et al*. (1986), who noted that the simplified Elovich equation was not applicable to P sorption and desorption probably, because they only tested published P sorption data obtained from conventional batch techniques with wide soil/solution ratios, that tend to minimize diffusion and transport processes.

Transformation in Added P under Saline Soil

Similar trend in P availability under saline soil (Farmer's field at Wachhoki in Hafizabad) was recorded as that of saline-sodic soil collected from SSRI Farm, Pindi Bhattian. The data in Fig. 1b indicated that P availability at the start of study was in the range of 11.95 to 24.75 ppm just after P application @ 20, 40 and 60 mg kg^{-1} soil under CR incorporation. It decreased gradually with the passage of time and at 120 days of incubation; it was the lowest in soil having no CR. As it has been discussed earlier, the overall decrease in P availability with the passage of time might have been due to its fixation, because of calcareousness (3.2% $CaCO_3$; Table 1). The results suggested that P fixation depended upon many factors and was a quite complex phenomenon. Ahmad *et al*. (1999) reported that in calcareous soils, P may be fixed on surface of Ca/Mg carbonates as well as in the Ca/Mg phosphate compounds and convert the added P into insoluble or less soluble phosphate compounds, which hinders its availability to plants. Similar findings have also been reported by Curtin *et al*. (1992), Oberson *et al*. (2001) and Javid and Rowell (2003). On the other hand, under CR incorporation its availability was significantly higher than that of the soil having no CR (Fig. 1b). From the results of our study, it is clear that incorporation of CR in soil enhanced P availability which could have been due to its release after their decomposition. However, the decrease in P sorption was not related to competition from the decomposition products of CR, but was the result of phosphorus release from the CR that started after 60 days of incubation and P availability was significantly higher than that of the soil without CR incorporation and showed significantly constant trend beyond 90 days of incubation. Similar results have also been discussed by Awad and Al-Obaidy (1989), Dhargawe *et al*. (1991), Bush and Austin (2001) and Nash *et al.* (2005).

Overall it is concluded that under saline sodic-soil, the P availability was comparatively higher than that of saline soil. Probably it was due to the presence of higher Na^+ concentration in the soil (Table 1), which formed sodium phosphate compounds that are soluble in nature.

Table 1: Physico-chemical analysis of the soils used for incubation study

Parameters	Unit	Soil-I	Soil-II
pH_s	–	8.29	8.18
EC_e	dS m^{-1}	6.59	4.21
SAR	–	17.39	6.57
OM (Walklay Black)	%	0.29	0.43
Total N	%	0.036	0.044
Total P (Olsen)	ppm	6.81	8.49
Extractable P (AB-DTPA)	mg kg^{-1}	2.97	2.76
Na^+	ppm	568	213
$CaCO_3$	%	3.47	3.21
Sand	%	60	45
Silt	%	30	18
Clay	%	10	37
Textural Class	–	Sandy Loam	Sandy Clay Loam
Soil Series	–	Rasulpur	Hafizabad

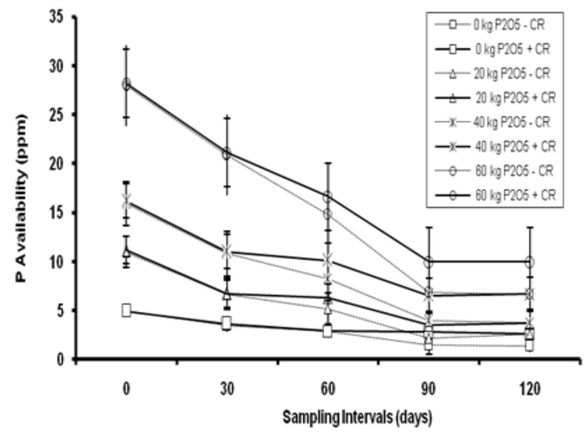

Fig. 1a: The P availability as affected by P application and CR incorporation under saline sodic soil

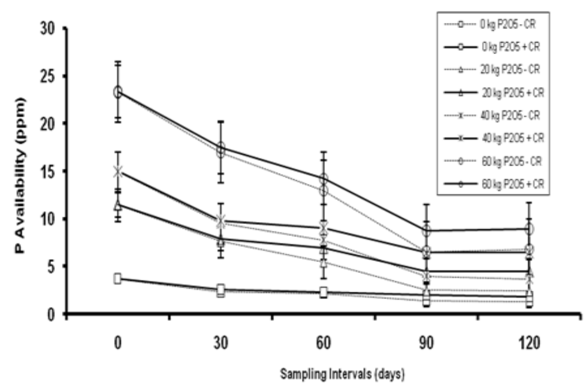

Fig. 1b: The P availability as affected by P application and CR incorporation under saline soil

Similar results have also been documented by Chhabra *et al.* (1982), Mahmood *et al.* (1994), Qadir, *et al.* (2003) and Ghafoor *et al.* (2004) who reported that in alkaline soils, most of the soil P was found in the form of soluble sodium phosphate compounds (NaH_2PO_4), which were absorbed by the plants causing reduction in plant growth and crop yields due to excess Na^+ uptake in the form of soluble sodium phosphate compounds. Wheat straw incorporation contributed more than P fertilizer in building up the P status of both saline-sodic and saline soils. Upon CR alone or combined with P fertilizer application, P availability was high. Earlier scientists also determined higher P availability in soil by using different organic materials and their findings supported present results (Aslam *et al.*, 1996; Pattanayak *et al*., 2001; Parmer and Sharma, 2002; Singh *et al*., 2002).

Electrical Conductivity (EC_e dS m^{-1})

Electrical conductivity is a soil parameter that indicates indirectly the total concentration of soluble salts and is a direct measurement of salinity. The data (Figs. 2a and b) indicated that EC_e of both soils was high which decreased significantly over the time under P application along with CR incorporation. Maximum EC_e was recorded from soils after incubation period having no CR. High EC_e in the absence of CR might be due to the fact that there was more evapotranspiration which caused salt concentration in media while, on the other hand, in CR amended soils there was comparatively less evapotranspiration causing decrease in EC_e. Crop residues had been reported to increase the soil amelioration process and improvement in soil physical conditions. Similar conclusions have also been reported by Abdullah *et al*. (2006).

In general, a decreasing trend in EC_e of both saline and saline-sodic soils was observed with CR incorporation in combination with phosphate fertilizer. The decomposition of CR released acids or acid forming compounds that reacted with the sparingly soluble salts already present in the soil and might have converted them into insoluble salts or at least decreased their solubility due which the EC_e of soil was decreased. Similar conclusions had also been reported by Pattanayak *et al*. (2001) and Singh *et al*. (2002).

Sodium Adsorption Ratio (SAR) ($mmol_c$ L^{-1})$^{1/2}$

The data (Figs. 3a and b) indicate that statistically the highest values of SAR [17.38 and 6.58 ($mmol_c$ L^{-1})$^{1/2}$] in both saline-sodic and saline soils, respectively was recorded at the begning of study which decreased gradually with the passage of time. After 60 days of incubation, minimum SAR value [16.54 and 6.44 ($mmol_c$ L^{-1})$^{1/2}$] of both the soils was observed with CR incorporation, which further decreased upto 120 days of incubation. As it had been dicussed earlier that the positive effect of CR after decomposition improved physical condition of the soils due to which the SAR values were lowered down.

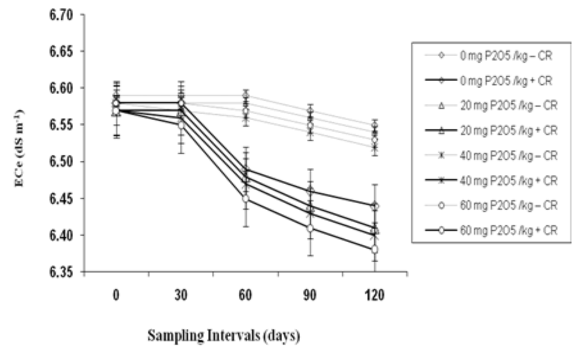

Fig. 2a: Soil EC_e (dS m^{-1}) as affected by P application and CR incorporation under saline sodic soil

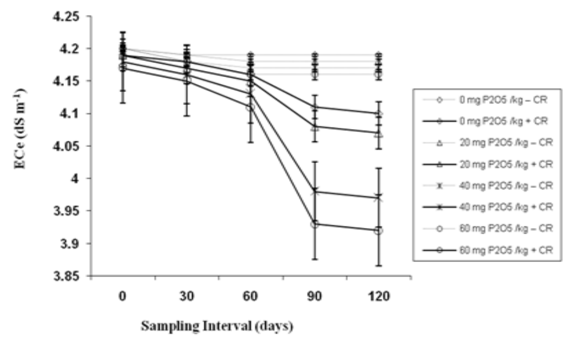

Fig. 2b: Soil EC_e (dS m^{-1}) as affected by P application and CR incorporation under saline soil

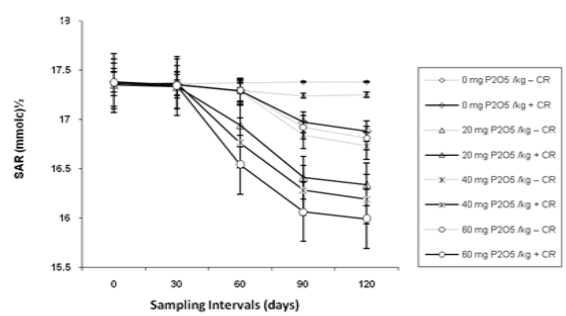

Fig. 3a: SAR ($mmol_c$ L^{-1})$^{1/2}$as affected by P application and CR incorporation under saline sodic soil

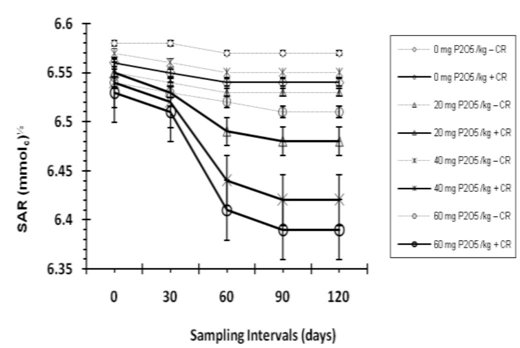

Fig. 3b: SAR ($mmol_c$ L^{-1})$^{1/2}$ as affected by P application and CR incorporation under saline soil

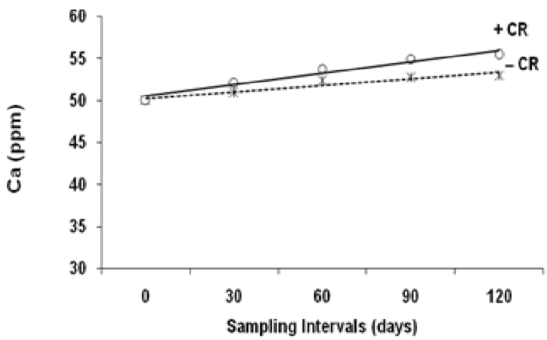

Fig. 4a: The Ca^{2+} concentration (ppm) of saline-sodic soil as affected by CR incorporation and P application

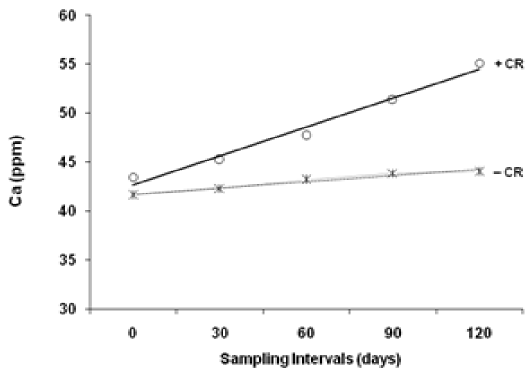

Fig. 4b: The Ca^{2+} concentration (ppm) f saline soil as affected by CR incorporation and P application

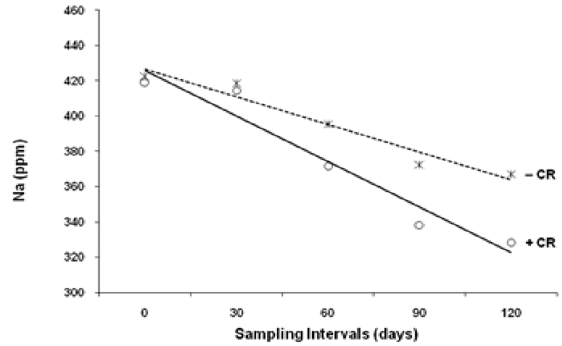

Fig. 5a: The Na^{+} concentration (ppm) of saline-sodic soil as affected by CR incorporation and P application

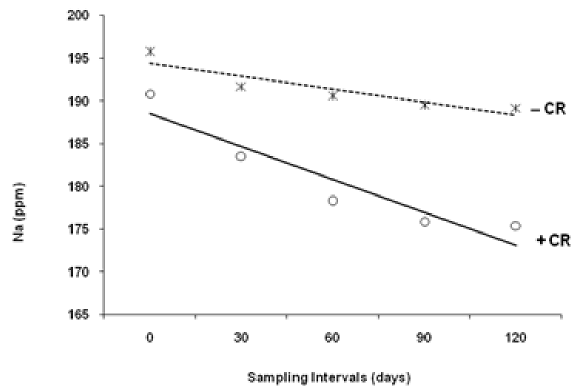

Fig. 5b: The Na^{+} concentration (ppm) of saline soil as affected by CR incorporation and P application

Most probably, the reason could be Na^{+} ions that might get fixed on organic residues and release of Ca^{2+} upon decomposition (Figs. 4a and b) have increased Na^{+}/Ca^{2+} ratio in the media due to which the SAR values of both the soils was droped significantly.

Incorporation of CR in combination with P application in both soils significantly lowered SAR over control where no CR was incorporated. All P treatments were at par among each other up to 30 days of incubation period but differed significantly beyond 60 days of incubation. Comparable results from application of P rates and CR incorporation were obtained, which differed significantly from control having no P and CR. Sodicity is the accumulation of Na^{+} ion in excessive quantities, which hinder plant growth directly or through the impairment of physical soil conditions. The effect of CR was favorable over control. The values of SAR become lesser either due to an increase in Ca^{2+} (Figs. 4a and b) or decrease in Na^{+} (Figs. 5a and b), which was favoured by CR after their decomposition. As discussed earlier, sodium salts being readily water soluble (Chhabra *et al*., 1982; Mahmood *et al*., 1994; Qadir, *et al.,* 2003; Ghafoor *et al*., 2004) left the soil system and the divalent cations (Ca^{2+}) increased the net concentration of the soil solution due to which the SAR decreased. Studies of Zaka *et al*. (2003) also indicated the same trend of decrease in soil SAR with the use of FYM, rice straw and sesbania green manure. They attributed the reduction in SAR of the soil with organic materials due to the release of organic acids causing mobilization of native calcium present as $CaCO_3$ in the soil.

Soil Ca^{2+} and Na^{+} Status

There were significant changes in Ca^{2+} status under both saline and saline-sodic soils (Figs. 4a and b). An increasing trend in soil Ca^{2+} was observed with CR incorporation as the time passed. However, the effect was more pronounced in saline soil than in saline-sodic soil. At 60 days of residues incorporation, its concentration in both the soils began to increase and remained highest even on 120 days of incubation.

Similarly, an opposite trend in Na^{+} status of both the soils was observed with time period under CR incorporation and P application (Figs. 5a and b). The highest concentration was noted in the beginning of incubation while it decreased gradually with the passage of time. This is in agreement with Qadir *et al*. (2003). Choudhary *et al*. (2011) concluded that organic materials (wheat straw and green manure) proved effective in mobilizing Ca^{2+} from inherent and precipitated $CaCO_3$ resulting in decline in soil EC_e and exchangeable Na^+. The long-term study proved that organic materials alone can be used to solubilize Ca^{2+} from inherent and precipitated $CaCO_3$ in calcareous soils for achieving sustainable yields in sodic soils grown in annual rotation.

Conclusion

It is concluded that after 60 days of incubation, both the soils (SSRI Farm, Pindi Bhattian and Farmer's field in Wachhoki, Hafizabad) were able to maintain 41 and 39% P, respectively in available form when P_2O_5 was applied @ 60 mg kg^{-1} with CR incorporation which was 11 and 9% higher, respectively as compared to the soils having no CR with the same P fertilizer level. An increasing trend in Ca^{2+} concentration in both the soils with CR incorporation was observed beyond 60 days of incubation and remained the highest even on 120 days of incubation. Overall, the CR incorporation not only improved P availability but also lowered EC_e (2% and 6%) and SAR (5% and 4%) of saline sodic and slightly salt-affected soils, respectively.

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