SOIL PHOSPHORUS FRACTIONS AND THEIR TRANSFORMATION IN NORMAL AND SALT AFFECTED SOILS AS AFFECTED BY ORGANIC AMENDMENTS

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The soil salinity causes physiological drought resulting in hindrance in the bio-availability of essential nutrients. The interaction between salinity and phosphorus uptake by plants is less explored. Two independent incubation experiments were conducted to study the distribution and transformation of various P fractions in normal and salt affected soils as influenced by various organic amendments application. In first experiment, three different levels of P (200, 400 and 600 mg kg^{-1} of soil) were applied in three soils differing in soil EC and SAR. Changes in various fractions of soil P (Ca_2-P, Ca_8-P, Al-P, Fe-P, Olsen-P) were estimated at different time intervals. All three soils behaved differently for P distribution among various fractions. Maximum available P (12.18 mg kg^{-1}) was found in PROKA soil (saline sodic) at 400 mg kg^{-1} of P applied. In 2nd experiment, various organic amendments [farmyard manure (FYM), poultry manure (PM), crop residue (CR)] and sewage sludge (SS) were used, with and without adding P fertilizer @ 400 mg kg^{-1} to study their effect on changes in soil P, at different time intervals. Plant available Olsen-P fraction significantly increased after 90 days in all soils (normal, saline sodic, marginal saline sodic) with amendments FYM and PM but not as much with amendments CR and SS. Overall, increase in Olsen-P was higher with PM (23.2, 21.7 and 19.4 mg kg^{-1}) and FYM (20.6, 17.6 and 20.6 mg kg^{-1}) as compared with SS (14.3, 15.5 and 15.7 mg kg^{-1}) and CR (12.9, 14.4 and 14.0 mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils, respectively. On the basis of these results, it was concluded that integration of PM and FYM with P level 400 mg kg^{-1} is an effective approach to mobilize more P available for plant uptake in normal and salt-affected soils with order of normal> saline sodic> marginal saline sodic.
Keyword: Soil salinity, ion toxicity, phosphorous bioavailability, soil fertility, organic amendments.

INTRODUCTION

Salinity is common environmental factor that adversely affect plant growth and crop production in cultivated areas worldwide (Singh *et al.*, 2011; Day *et al.* 2015). Soil salinity is a major factor for decreasing crop growth and yield due to osmotic stress (Koksal *et al.*, 2016; ; Sherani *et al.*, 2017; Wahid *et al.* 2017) followed by ion toxicity (Rahnama *et al.*, 2010; James *et al.*, 2011; Akram *et al.*, 2017), hence it may cause ionic imbalance in plants and changes in nutrient bioavailability in soil.

Phosphorus deficiency in arable land limits 30-40% of crop productivity (Vance *et al.*, 2003) and is prevalent in calcareous soils and arid climates simultaneously with salinity problem. As salt stress influences the soil condition i.e. EC, SAR, pH, structure, aeration etc., hence may affect P availability. Moreover, continued and high rate of application of P fertilizers could lead to accumulation and transformation of available soil P fractions into unavailable ones (Lai *et al.*, 2003). This effect of P application varies with soil type and climate as well as the amount of P applied (Zhang *et al.*, 2004).

Phosphorus is present in soils in various forms and the knowledge of different geochemical fractions of P in soil is important for determining long term P availability in soil. Sequential extraction techniques has been widely used for predicting P bioavailability, leachability and transformations of different chemical forms in agricultural and polluted soils (Sui *et al.*, 1999). The inter-relationships among the various P fractions in various soils are complex. Upon application of organic and inorganic P sources, the various fractions of P could be dissolved and form secondary complexes (Hua *et al.*, 2016). Hence, knowledge about these fractions may increase our understanding for an efficient P management program.

Salt-affected soils offer more restrictions for P bioavailability than normal soils (Qadir *et al.*, 2005). It is needed to elucidate the redistribution of various soil P fractions with different P application rates that has not been widely studied (Murtaza *et al.*, 2015). Moreover, the changes in P fractions in salt affected soils have not been studied widely, particularly in Pakistan. Sorption of P by soil colloids is the principal factor influencing plant availability of P mineralized from crop residues (Jalali and Ranjbar, 2010). In salt-affected soils, P is one of the major limiting nutrients which often have high

fixing capacity and precipitation reactions with Ca, Al and Fe oxides, thus transferring into relatively insoluble complexes (Lai *et al.,* 2003). The P use efficiency in such soils is about 10–15% and can be improved after adding organic amendments (Tisdale *et al*. 2012; Sharma *et al*., 2002). Calcium phosphate (Ca-P) is the most dominant P fraction in saline or saline-sodic soils (Meena *et al*., 2018). In saline sodic soil, integration of organic amendments, e.g. poultry manure, crop residue and farmyard manure have shown increase in reclamation efficiency and availability of nutrients especially P for plant nutrition (Choudhary *et al*., 2007; Rawat *et al*., 2013; Meena *et al.*, 2018).

The remediation of such soils using organic amendments (FYM, PM, CR SS) is promising and has shifted the attention from sole use of chemical fertilizers (Maillard and Angers, 2014). The physico-chemical and biological properties of salt affected soils could be improved by the application of chemical and organic fertilizers for sustainable crop productivity (Ghafoor *et al*., 2004; Wong *et al*., 2009). Fertilization practices combined with organic amendments could not only sustain but can increase crop yield and soil fertility (Maillard and Angers, 2014). However, the responses of soil P availability and P accumulation are variable under different organic amendments.

The re-distribution of the different P fractions and soil P availability could be enhanced by organic amendments (Debicka *et al*., 2016). However, the transformations of P forms in soils amended with FYM, PM, CR and sewage sludge (SS) are not clear, limiting effective P management practices in the agricultural systems (Audette *et al*., 2016) particularly in salt affected soils.

Specific objective of this study was to determine different P fractions in normal and salt affected soils and their re-distribution over time with different rates of P fertilizer application and to determine integrated effect of organic and inorganic amendments on P availability in three soils differing in salinity/sodicity stress.

MATERIALS AND METHODS

Two independent studies were conducted in the wire house of the Institute of Soil and Environmental Sciences (ISES), University of Agriculture (UAF) Faisalabad (latitude 31.4181, longitude 73.0778), Pakistan. Soil used in experiment was collected from three different sites differing in salinity stress, 1) field area of ISES, UAF, 2) PROKA farm, UAF. Faisalabad, 3) Postgraduate Agriculture Research Station (PARS), UAF. Faisalabad, Pakistan. Before conducting experiments, soil was air dried and analyzed for physico-chemical properties after removing pieces of stone and straw passing through a 2-mm sieve. The physico-chemical properties of soils are given in Table 1 and P fractionation of original soil samples are given in Table 2. Quantitative measurement of various P fractions was done following Jiang and Gu (1989). Briefly, Ca_2-P was extracted by $NaHCO_3$, Ca_8-P was extracted by NH_4-acetate treatment, the 0.5 N NH_4-F treatments extracts aluminum phosphate (Al-P) and the $NaOH$–Na_2CO_3 solution mixture extracts iron phosphate (Fe-P).

For 1st experiment, each experimental pot was filled with 3 kg soil of each soil type. Three rates of P (200, 400 and 600 mg kg^{-1}) were employed using di-ammonium phosphate (DAP)

Table 1. Physico-Chemical properties of three different soils at the start of experiment.

Parameters	Units	Normal soil (UAF)	Saline sodic soil (PROKA)	Marginal Saline sodic soil (PARS)
Texture (Gee and Bauder, 1986	--	Sandy clay loam	clay loam	clay loam
pH	--	7.90	8.80	8.20
EC_e	dS m^{-1}	1.89	11.18	5.90
SAR	(mmol $L^{-1})^{1/2}$	7.90	34.80	19.60
O.M (Jackson, 1962)	%	0.60	0.47	0.52
N	mg kg^{-1}	40.00	29.00	34.00
P (Watanabe and Olsen, 1965)	mg kg^{-1}	5.70	8.10	6.30
K	mg kg^{-1}	120.00	112.00	127.00
CEC	$Cmol_c$ kg^{-1}	11.20	12.90	12.20
Na^+	g kg^{-1}	1.60	2.70	2.20
Ca^{++}	g kg^{-1}	1.00	1.40	1.30

Table 2. Phosphorous fractionation of original soils at start of the experiment.

Soil	Ca_2-P	Ca_8-P	Al-P	Fe-P	Olsen-P
			mg kg^{-1}		
Normal (UAF)	17.65	20.60	9.32	11.12	5.89
Saline sodic (PROKA)	11.05	12.88	14.75	12.65	9.05
Marginal Saline sodic(PARS)	12.65	13.88	13.52	16.55	6.95

Table 3. Initial chemical properties of organic amendments.

Parameters	Units	FYM	PM	CR	SS
C:N ratio	--	10.1	17.6	12.8	14.4
Ph	--	8.2	7.8	8.0	8.4
O.M	%	15.6	20.5	17.8	14.1
Mg	g kg^{-1}	2.0	2.7	2.3	3.1
EC	"	2.2	3.1	2.6	3.5
SAR	(mmol L^{-1})$^{1/2}$	2.8	3.7	3.4	4.9
Cl	g kg^{-1}	3.2	4.8	3.7	5.3
Total N	"	13.5	17.9	12.6	15.1
Total P	"	2.5	2.9	2.4	2.1
Total K	"	4.2	4.9	5.3	3.6
CEC	Cmol$_c$ kg^{-1}	23.0	29.0	19.9	20.7
Na	g kg^{-1}	2.3	3.6	1.9	2.8
Ca	"	1.1	2.3	1.3	2.7

FYM=farmyard manure, PM= poultry manure, CR= crop residue, SS= sewage sludge

as P fertilizer source. Samples were placed at room temperature by using CRD design. Different fractions of P i.e., (Ca$_2$-P, Ca$_8$-P, Fe-P, Al-P and Olsen-P) were determined after 0, 5, 10, 15, 30, 60 and 90 days.

In 2nd experiment, Farmyard manure (FYM), poultry manure (PM), crop residue (CR) and sewage sludge (SS) were used as organic amendments. Farmyard manure was collected from dairy farm of UAF and PM was collected from poultry farm of UAF. Wheat crop residue (CR) was collected from field area of ISES, UAF. Aerobically processed sewage sludge was obtained from wastewater treatment plant Islamabad (latitude 33.65, longitude 73.05), Pakistan. The properties of organic amendments are presented in Table 3. Each experimental pot was filled with 3 kg soil of each type. Phosphorous was applied at 400 mg kg^{-1} using di-ammonium phosphate (DAP) as P fertilizer source (rate selected from previous study on the basis of availability of Olsen-P). Farmyard manure (FYM), poultry manure (PM), crop residue (CR) and sewage sludge (SS) were used as organic amendments and employed at 1% (w/w). Different fractions of P i.e., (Ca$_2$-P, Ca$_8$-P, Fe-P, Al-P and Olsen-P) were determined after 0, 5, 10, 15, 30, 60 and 90 days.

Statistical analyses: To conduct all experiments, completely randomized block design was used. Each sub-block was divided into three repeats. The data obtained was subjected to two-way analysis of variance (ANOVA) using Statistix 8.1 software. Significance difference of treatment means were separated by using LSD test (P<0.05).

RESULTS

Initial soil analysis before the start of experiment showed that P fractions vary significantly, and maximum P was retained as octa calcium phosphate (Ca$_8$-P) (20.6 mg kg^{-1}) followed by Ca$_2$-P (17.65 mg kg^{-1}), Fe-P (11.12 mg kg^{-1}) and Al-P (9.32 mg kg^{-1}) fraction in normal soil. Available P (Olsen-P) was found minimum as 5.89 mg kg^{-1} in same soil (Table 2). In

saline sodic soil, maximum P was retained as Al-P (14.75 mg kg^{-1}) followed by Ca$_8$-P (12.88 mg kg^{-1}), Fe-P (12.65 mg kg^{-1}) and Ca$_2$-P (11.05 mg kg^{-1}) fractions. While minimum P was found as Olsen-P fraction (9.05 mg kg^{-1}) in the same soil. In marginal saline sodic soil, maximum P was retained as Fe-P (16.55 mg kg^{-1}) followed by Ca$_8$-P (13.88 mg kg^{-1}), Al-P (13.52 mg kg^{-1}) and Ca$_2$-P (12.65 mg kg^{-1}) fractions. While minimum P was found as Olsen-P (6.95 mg kg^{-1}) in same soil. By comparing these soils, maximum P contents were found in normal soil while maximum available P (Olsen-P) was found in saline sodic soil (9.05 mg kg^{-1}), followed by marginal saline sodic (6.95 mg kg^{-1}) and normal soil (5.89 mg kg^{-1}), respectively (Table 2).

Phosphorus application significantly increased P concentration in all three soils. Maximum increase in di-calcium phosphate (Ca$_2$-P) fraction was found at P application level 400 and 600 mg kg^{-1} especially in normal soil up to 90 days (Fig. 1). But this increase after five days was not found significant in salt affected (saline sodic and marginal saline sodic) soils. Di-calcium phosphate (Ca$_2$-P) fraction increased maximum up to 37.95 mg kg^{-1} in normal, 26.01 mg kg^{-1} in saline and 22.98 mg kg^{-1} in saline sodic soil, when P was applied at 600 mg kg^{-1} rate (Fig. 1). No change was observed in all un-amended soils (control).

Similarly, Octa-calcium phosphate (Ca$_8$-P) fraction significantly increased in all soils with P application (Fig. 2). Results depicted that Ca$_8$-P concentration significantly increased in all soils as the P level increased. But this increase was highest up to 90 days of incubation in normal soil, as compared to saline sodic and marginal saline sodic soils at P application level 600 mg kg^{-1}. After 90 days, Ca$_8$-P fraction increased up to 44.6 mg kg^{-1} in normal, 29.75 mg kg^{-1} in marginal saline sodic and 27.23 mg kg^{-1} in saline sodic soil, at 600 mg P kg^{-1} of soil (Fig. 2). No change was observed in all un-amended soils (control).

Aluminum-phosphate (Al-P) fraction significantly increased in all soils as the P application rate increased (Fig. 3). Results

depicted that after 90 days, Al-P fraction significantly increased at P application levels (400 and 600 mg kg⁻¹) in saline sodic and marginal saline sodic soils, as compared to normal soil (Fig. 3). While a non-significant change observed in all un-amended soils (control).
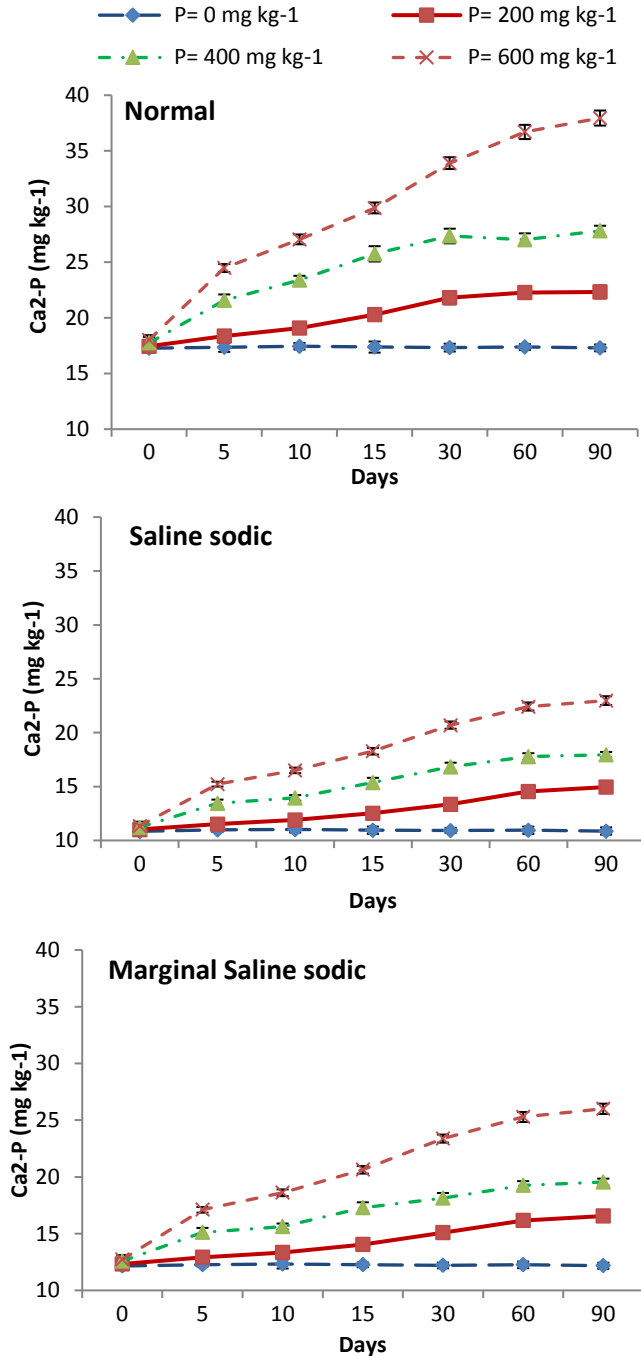

Figure 1. Di-calcium Phosphate (Ca₂-P) concentrations in normal, saline sodic and marginal saline sodic soils with and without added P fertilizer.
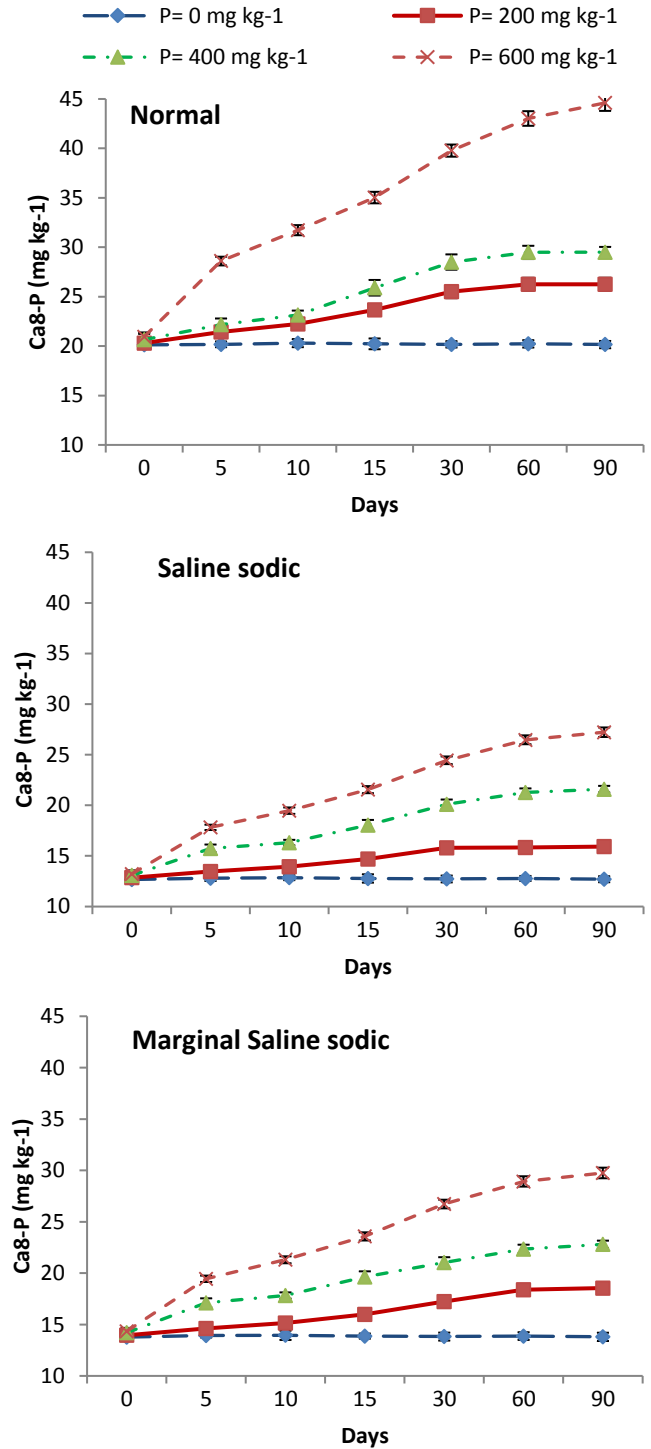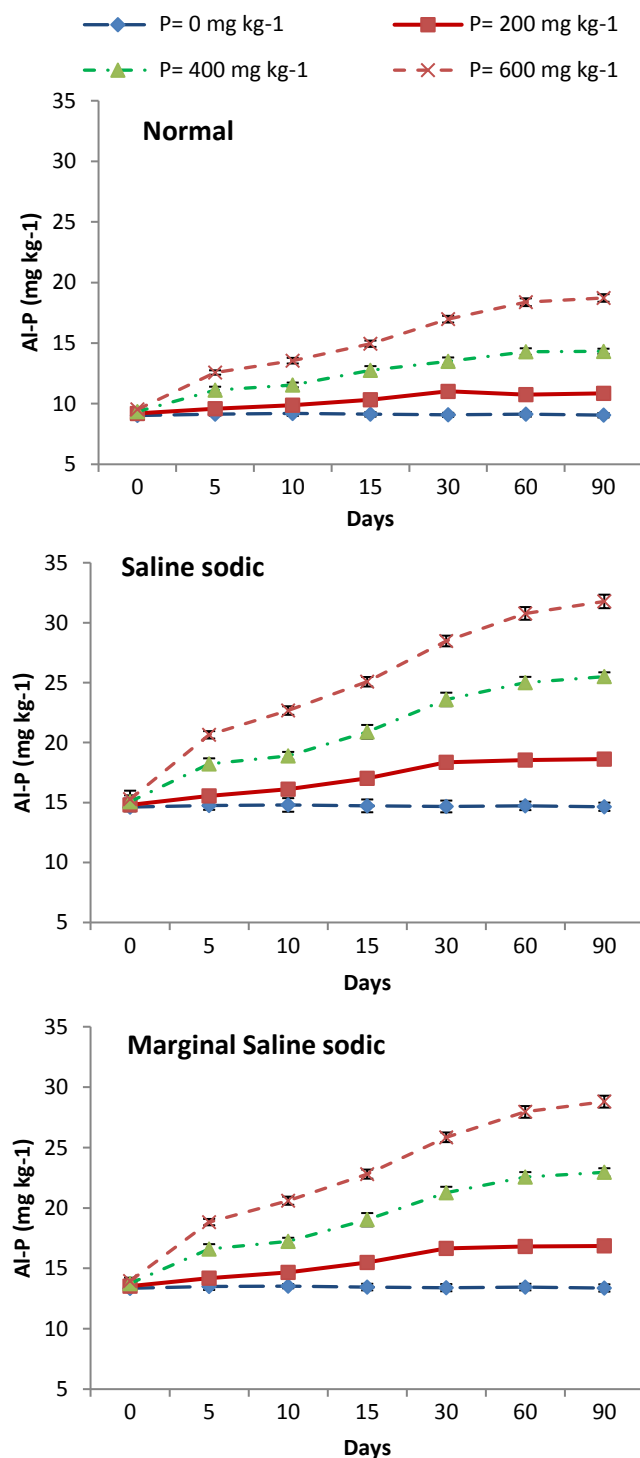

Figure 2. Octa-calcium Phosphate (Ca₈-P) concentrations in normal, saline sodic and marginal saline sodic soils with and without added P fertilizer.

Figure 3. Aluminum-Phosphate (Al-P) concentrations in normal, saline sodic and marginal saline sodic soils with and without added P fertilizer.

Similar trend was shown in iron phosphate (Fe-P) fraction. It was significantly increased in all soils as the P application rate increased (Fig. 4). Results depicted that for initial few days, Al-P fraction significantly increased in all soils at P application level (400 and 600 mg kg^{-1}). But this increase was found highest until 90 days in saline sodic and marginal saline sodic soils, as compared to normal soil at P application level 600 mg kg^{-1} of soil. After 90 days, Fe-P fraction increased up to 35.2 mg kg^{-1} in marginal saline sodic, 27.03 mg kg^{-1} in saline sodic and 22.78 mg kg^{-1} in normal soil at application of 600 mg P kg^{-1} of soil (Fig. 4). While a non-significant change observed in all un-amended soils (control).

On the contrary, Olsen-P fraction showed a different trend for its availability in all soils, as time proceeded (Fig. 5). It increased significantly for initial 15 days with P application in all soils and its value started to decrease after 15 days at all P application levels (200,400 and 600 mg kg^{-1} of soil). But its value decreased slowly until 90 days at P application level 400 mg kg^{-1} of soil. In general, maximum Olsen-P was found 12.18 mg kg^{-1} in saline sodic soil, 9.23 mg kg^{-1} in marginal saline sodic soil and 9.13 mg kg^{-1} in normal soil at P application level 400 mg kg^{-1} of soil after 90 days (Fig. 5). While distribution of Olsen P remained same in control (un-amended soils). So this level of P application (400 mg kg^{-1}) was used in combination with organic amendments for next study of 90 days.

The results after 90 days showed that re-distribution of di-calcium phosphate (Ca$_2$-P) fraction significantly affected by different organic amendments application at P application level 400 mg kg^{-1} of soil (Fig. 6). Di-calcium phosphate (Ca$_2$-P) concentration increased linearly with time in normal soil and highest increase (24.5 mg kg^{-1}) was observed with application of crop residue (CR). In saline sodic soil, Ca$_2$-P fraction was increased with sewage sludge amendment for initial 5 days but afterwards its highest concentration (21.1 mg kg^{-1}) was recorded with CR amendment. In marginal saline sodic soil, change in Ca$_2$-P concentration was found variable with initial increase for 30 days. Later on, its concentration decreased at the end of 90 days with application of all amendments. In contrast, a non-significant change in Ca$_2$-P fraction was observed in all un-amended soils (control) after 90 days.

Concentration of octa-calcium phosphate (Ca$_8$-P) fraction also differed significantly by different organic amendments at P level 400 mg kg^{-1} of soil (Fig. 7). Octa-calcium phosphate (Ca$_8$-P) concentration was increased linearly with time and highest increase was observed with CR amendment in normal and saline sodic soil. Interestingly, its concentration increased with amendments farm yard manure (FYM) and poultry manure (PM) for initial 60 days of incubation and then decreased in all soils. Same trend of Ca$_8$-P distribution was shown with amendment CR in marginal saline sodic soil. A non-significant change in Ca$_8$-P fraction was observed in all un-amended soils.
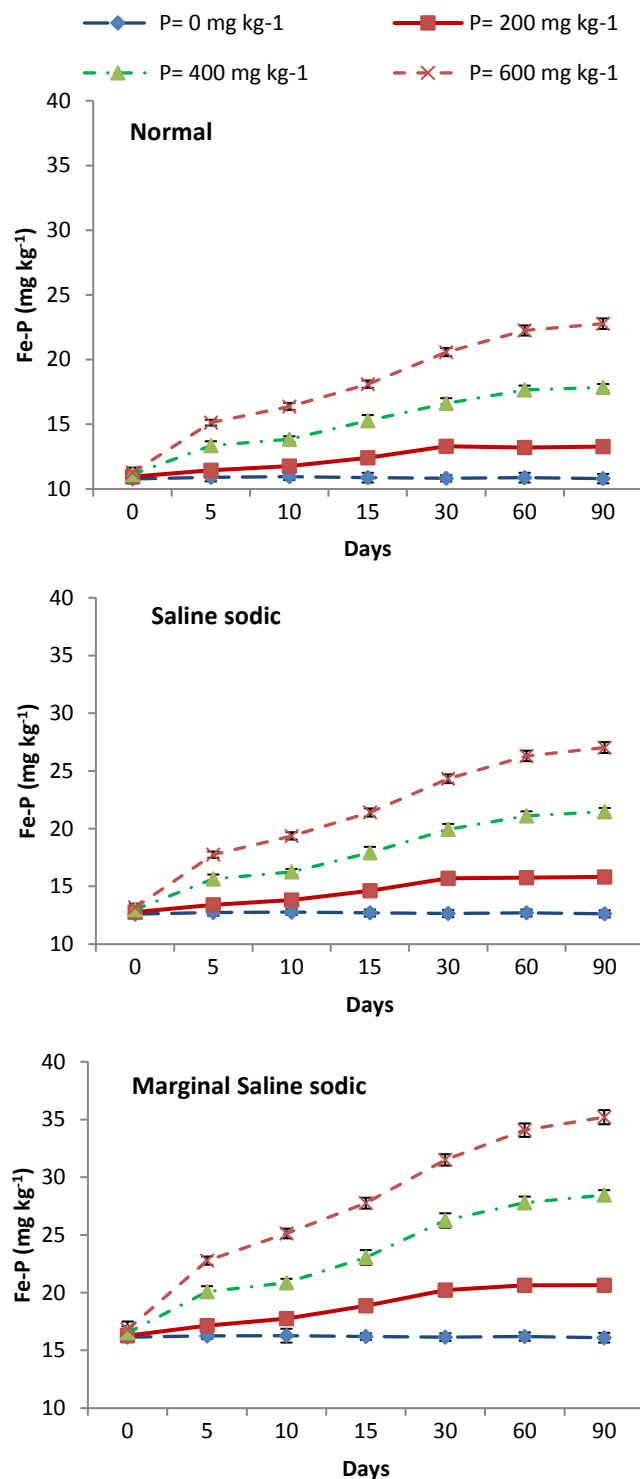
Figure 4. Iron-Phosphate (Fe-P) concentrations in normal, saline sodic and marginal saline sodic soils with and without added P fertilizer.
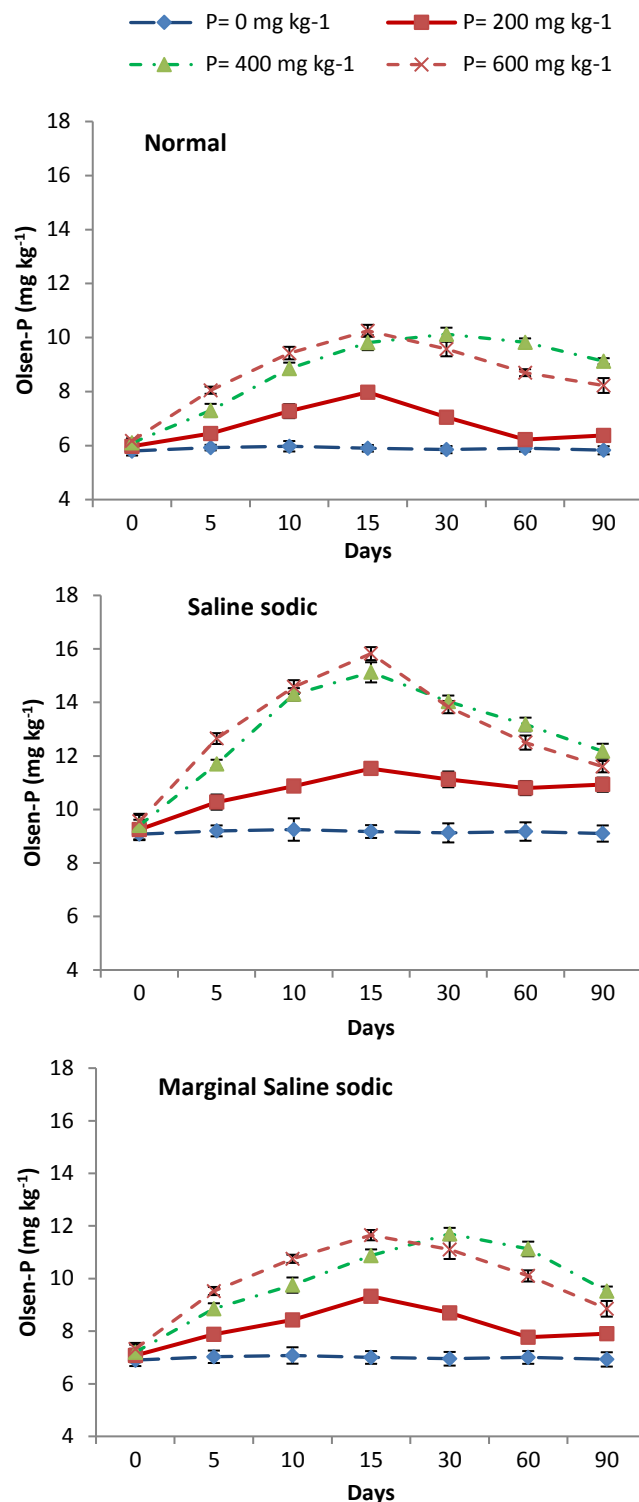
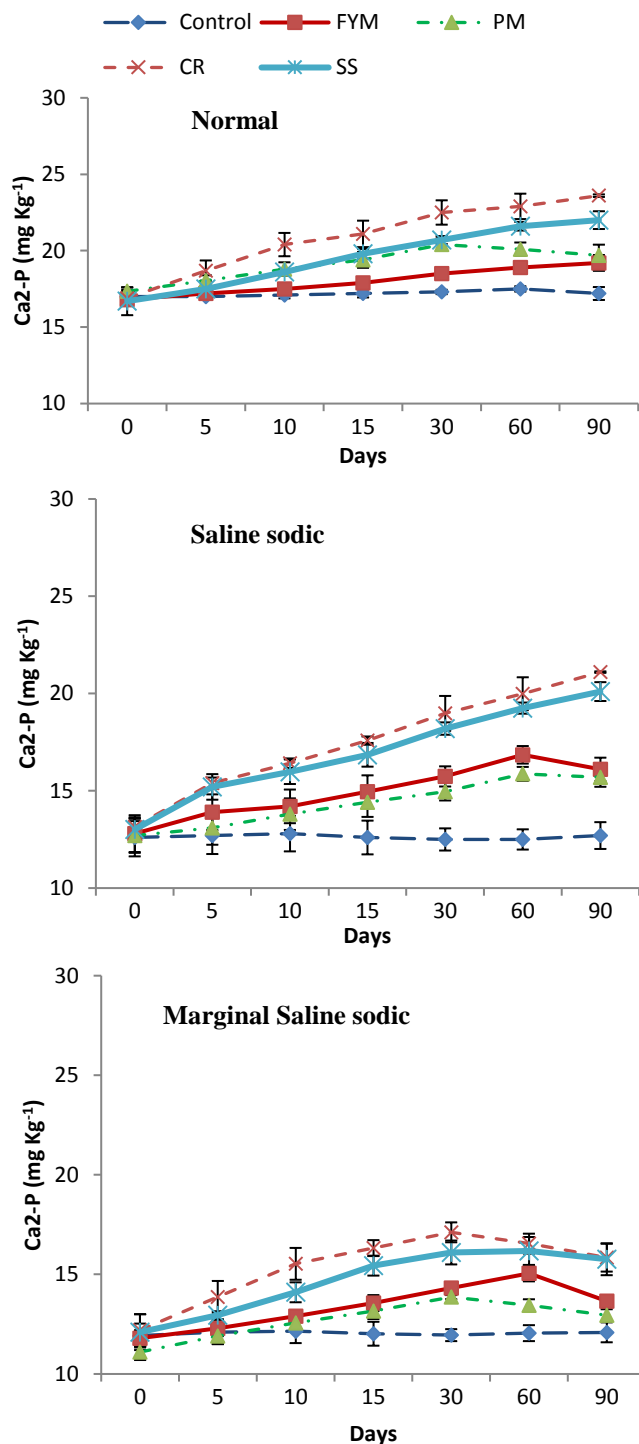**Figure 5. Olsen-P concentrations in normal, saline sodic and marginal saline sodic soils with and without added P fertilizer.**

Figure 6. Changes in Di-calcium Phosphate (Ca$_2$-P) concentration (mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils at P level (400 mg kg^{-1}) with different organic amendments
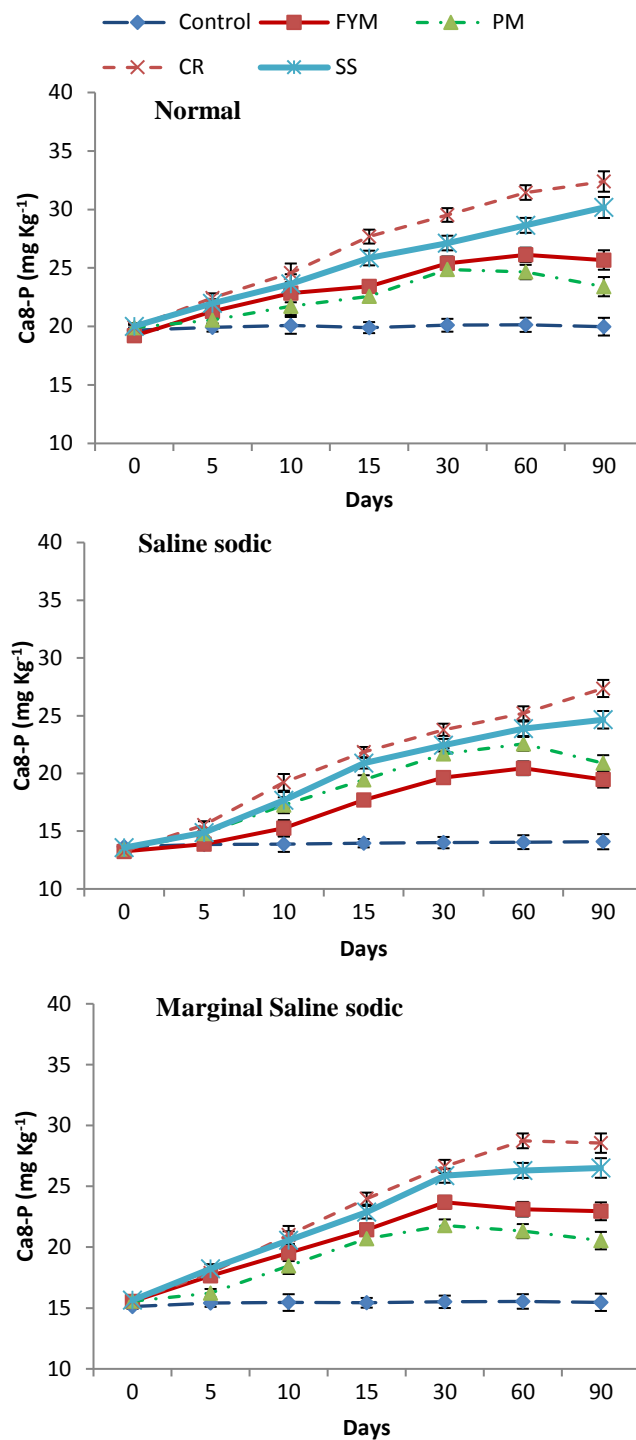
Figure 7. Changes in Octa-calcium Phosphate (Ca$_8$-P) concentration (mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils at P level (400 mg kg^{-1}) with different organic amendments
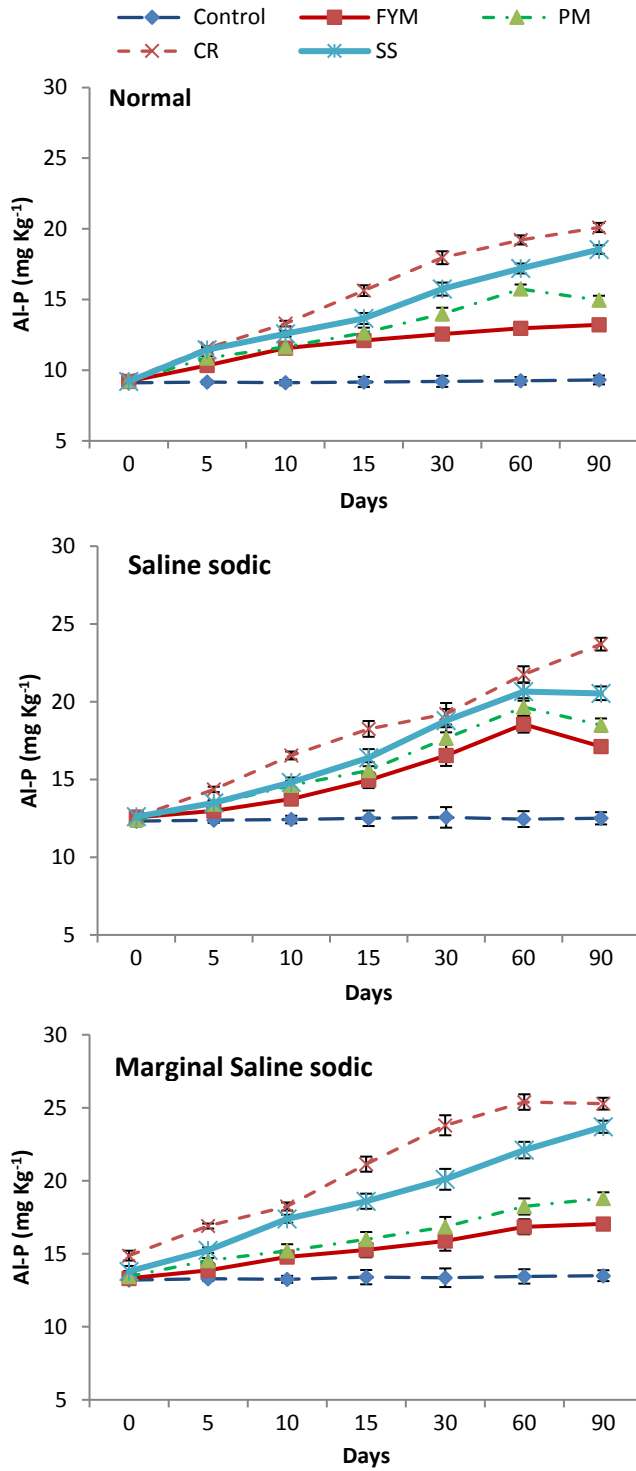
Figure 8. Changes in Aluminum Phosphate (Al-P) concentration (mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils at P level (400 mg kg^{-1}) with different organic amendments
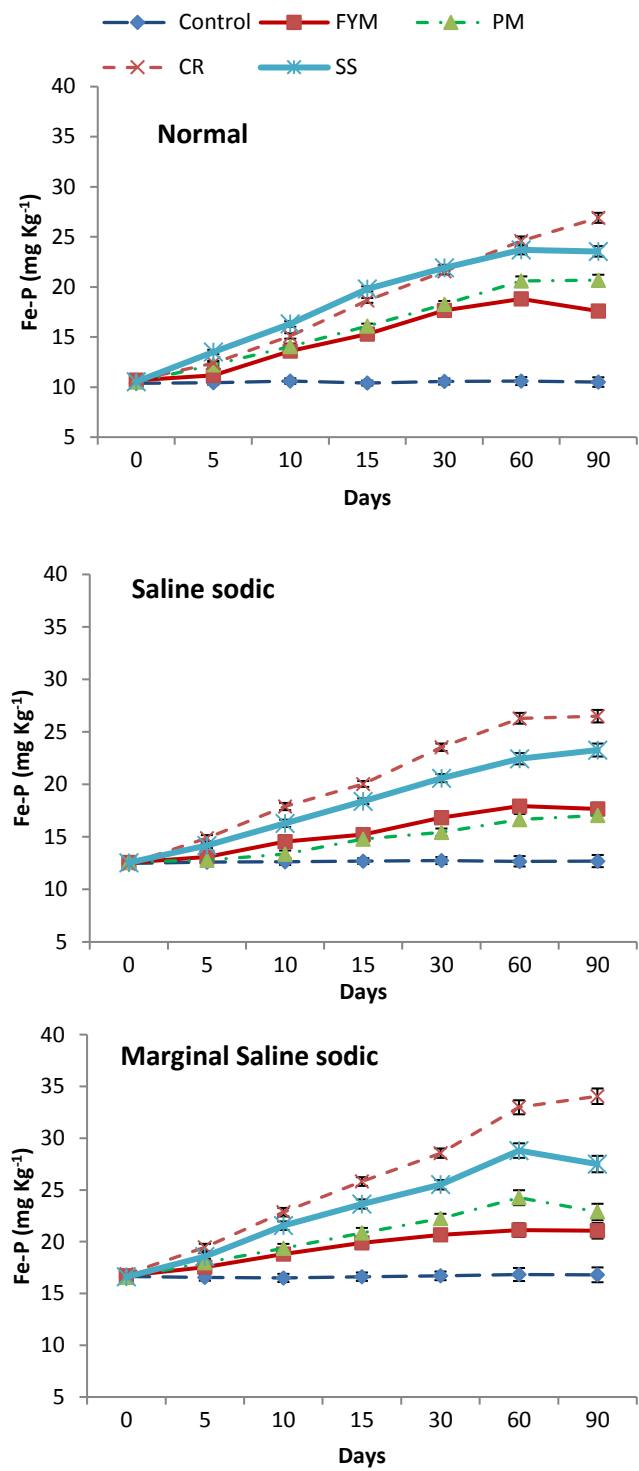
Figure 9. Changes in Iron Phosphate (Fe-P) concentration (mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils at P level (400 mg kg^{-1}) with different organic amendments.

In general, aluminum phosphate (Al-P) concentration increased after 90 days but its distribution was different in all soils with applied amendments. In normal soil, Al-P concentration increased uniformly with all treatments for initial 5 days. After that, its concentration increased linearly with time and found highest with treatments CR and sewage sludge (SS). While in case of saline sodic soil, Al-P concentration increased up to 60 days and then decreased with the application of all treatments except CR. With CR application, Al-P concentration reached maximum (25 mg kg^{-1}), but then declined after 60 days. No change in Al-P fraction was observed in all un-amended soils after 90 days (Fig. 8).

In normal soil, Fe-P concentration increased up to 60 days and then decreased in all treatments except CR with a maximum value 26.6 mg kg^{-1}. In case of saline sodic soil, all treatments increased Fe-P concentration linearly with time. Marginal saline sodic soil showed different response with increased Fe-P concentration for 60 days and then decreased afterwards with all treatments (Fig. 9).

Overall, proportion of available P (Olsen-P) increased significantly with the application of all organic amendments but the rate of increase was different in all soils. Application of poultry manure (PM) increased the concentration of Olsen-P highest in normal and saline sodic soils and farm yard manure (FYM) increased this P fraction in marginal saline sodic soil. Proportion of Olsen-P after 60 days implies that during the decline of other P fractions, concentration of available P increased, thus maintaining a complex equilibrium. A non-significant change in Olsen-P fraction was observed in all un-amended soils (Fig. 10).

DISCUSSION

Agriculture and human activities are considered as main source for change in modern terrestrial P cycle (Curtis *et al.*, 2008). The use of chemical P fertilizers is needed in agricultural soils due to low concentration and non-mobile P, to increase plant growth and yield. After application to soil, P fertilizers undergo three types of reaction including direct reaction, adsorption reaction, and precipitation reaction (Havlin *et al.*, 2011). The availability of P is short lived in soils due to high P sorption reactions (Couto *et al.*, 2017). Such sorption of added P with Ca contents is highly affected by the chemistry and mineralogy of soil, and their impact on P availability is greater in soils with high P sorption rate. These reactions determine the availability of P in most ecosystems (Mishra *et al.*, 2013). In calcareous soils, P retention is governed by precipitation reactions (Lindsay *et al.*, 1989), with $CaCO_3$ (Larsen, 1967) and clay minerals (Devau *et al.*, 2010). Phosphorus can also precipitate with soluble calcium, generating Ca_2-P. Later on, this Ca_2-P can be changed into more stable forms such as Ca_8-P which is unavailable to plants (Arai and Sparks, 2007).
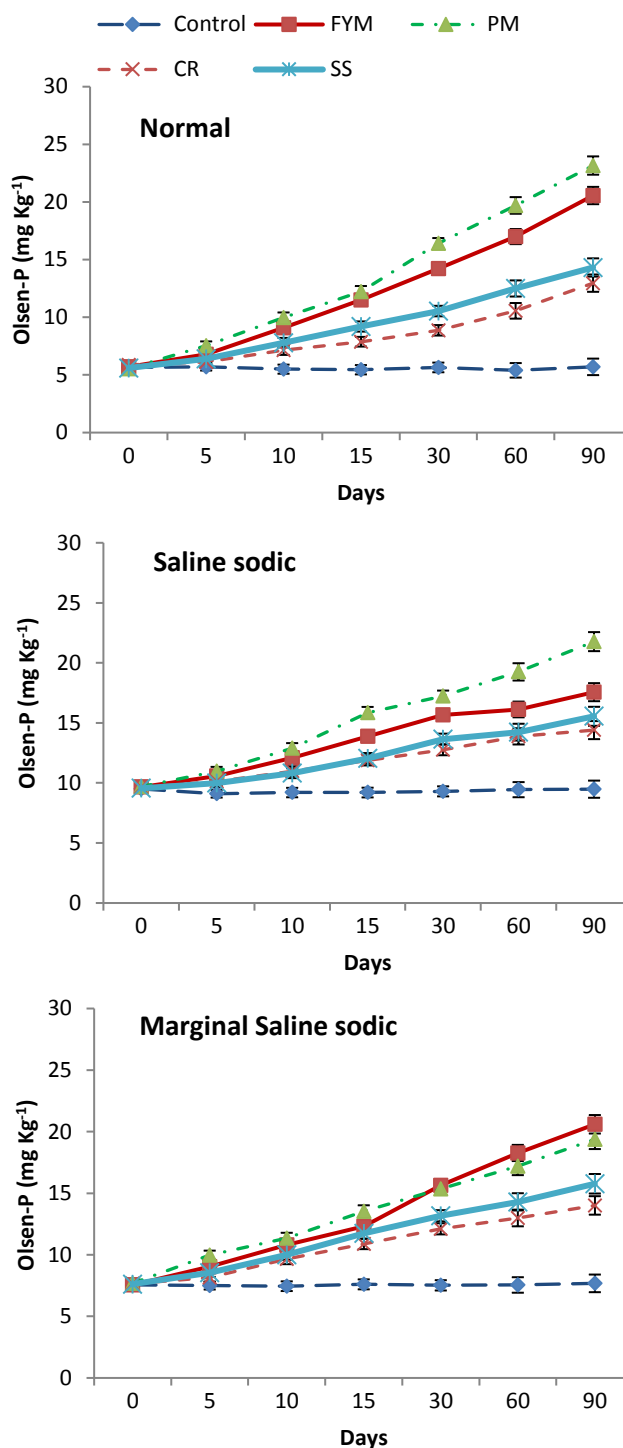

Figure 10. Changes in Olsen P concentration (mg kg^{-1}) in normal, saline sodic and marginal saline sodic soils at P level (400 mg kg^{-1}) with different organic amendments.

Jalali and Ranjbar (2010) reported that different P fractions might differ remarkably in their bioavailability and chemical behavior. Hence understanding of these transformations is needed for proper management of P in calcareous and problematic soils.

Application of P fertilizer and their combinations with organic materials generally enhanced the amount of P fractions in the form of Ca-P, Al-P and solid P significantly (Singh *et al.*, 2005). Park *et al.* (2004) reported that compost significantly increased P fraction Ca-P in comparison to the control (un-amended soil).

Initially, application of P at 400 and 600 mg kg^{-1} in normal soil significantly increased Ca$_2$-P, but rate of increase was reduced later on after 5 days and remained almost similar till 15 days and both treatments differed significantly after 15 days as increase was very high in case of 600 mg kg^{-1}. Similar trend was also found by Ca$_8$-P fraction in normal soil but its rate of increase was higher as compared to Ca$_2$-P at P application level 600 mg kg^{-1}. Maximum increase in Ca-P fractions in normal soil as compared to saline sodic and marginal saline sodic soils might be due to P fixation and precipitation with CaCO$_3$ and other soil colloids. Similar results were also reported by Lai *et al.* (2003), that increased P fertilizer application directly increased the proportion of Ca$_2$-P (1.1%-2.2%), Ca$_8$-P (16.6%-32.7%) and Al-P (2.4%-7.7%) while the proportions of Fe-P (6.3%-7.8%) and occluded P (2.7%-3.5%) remained stable after the incubation period. They concluded that progressive mineralization and immobilization reactions increased when P is added as a fertilizer. Increase in Ca$_2$-P is less in saline sodic and marginal saline sodic soils than in normal soil at all P application rates (Fig. 1). It might be due to increased precipitation reactions of P with Ca contents and hence P availability was decreased. The decrease in P availability might be due to its fixation on soil colloids as P might be fixed on to the surface of Ca/Mg carbonates, which converts added P into less soluble phosphate compounds (Ahmad and Khan, 2010). These fractions can be released via mineralization reactions through soil organisms and plant roots.

In saline sodic and marginal saline sodic soils, the added P converted more to Al-P form than in Ca$_2$-P or Ca$_8$-P. It might be due to the fact that P fixation can be dominantly by Al and Fe oxides and hydroxides, such as goethite, gibbsite and hematite (Damon *et al.*, 2014). Iron oxide or Al oxide and clay minerals have large specific surface areas, which provide large number of adsorption sites (Arai and Sparks, 2007). Similar trend was shown by Fe-P in saline sodic and marginal saline sodic soils at high P application level (600 mg kg^{-1}).

Overall, Olsen-P content in the soil without fertilizer P application remained same after 90 days. Its concentration increased for initial 15 days with all P application levels but then decreased with time in a complex equilibrium. Its decrease in concentration after 15 days is inconsistent with the increasing concentration of other P fractions during later stages. Jalali and Ranjbar (2010) also found a sharp decrease in Olsen-P within 3 days after P addition.

In this experiment, Olsen-P was found higher at P application level of 600 mg kg^{-1} than P application level of 400 mg kg^{-1} up to 15 days but later on, P application level of 400 mg kg^{-1} provide higher Olsen P than all other P application levels. It might be due to adequate P fertilization that provides adequate P availability. Xie *et al.* (1991) observed that Olsen-P content was considerably higher in treatments with animal fertilizer. Ma *et al.* (2009) also found that the Olsen-P concentration in soils increased with P fertilizers application, mainly due to P fertilization rate and soil pH reactions.

Addition of organic amendments also indirectly influenced the availability of P within the soil P pool (Chun *et al.*, 2007). The addition of CR and SS increased Ca-P contents consistently in all experimental soils, which may be related to formation of Ca-P complexes through chelation and precipitation reactions. Organic matter alters soil pH and increases the net negative charge surfaces in soil, with the net effect of increased solubility and reduced sorption of P in soil by increasing P diffusion rate (Cong and Merckx, 2005). In addition, decomposition of PM and FYM derived organic residues produce humic and fulvic acid which can compete with solution P for sorption sites of clay mineral (Meena and Biswas, 2014). Poultry manure and farmyard manure are rich in nutrients and enhance P availability in salt affected soil via solubilization of adsorb P from mineral sites due to which liable pool of P increased (Mahmoodabadi and Heydarpour, 2014; Oustani *et al.*, 2015) further sewage sludge (SS), also enhance P nutrition in problem soil (Ashraf *et al.*, 2016).

Greater accumulation of Fe-P and Al-P contents in salt-affected PROKA and PARS soils demonstrated that organic P compounds are readily adsorbed onto iron oxides and aluminum oxides (Anderson *et al.*, 1974). Immobilization of soil P occurs when the total P of the residue is insufficient to meet the P requirements of the microbial biomass. Organic acids generated by the higher microbial activity associated with composts reduced P adsorption sites and increased extractable P content in soil-compost mixture (Sikora and Enkiri, 2003).

On the other hand, increase in Olsen-P fraction after 30 days of organic amendments application seems to be released from Ca-P fractions as stated by Wang (2008). The ability of Ca-P to transform into Olsen-P was greatly enhanced by application of PM. However, it depends on the P concentration in the residues as it becomes mineralized (Damon *et al.*, 2014; Hua *et al.*, 2016).

***Conclusion*:** It is concluded that P distribution in all the three types of soils has a significant variation at all P fertilizer levels. Overall, P application at 400 mg kg^{-1} was found most effective in enhancing available-P (Olsen-P) in all soils. Poultry manure and farmyard manure addition enhanced the release of available P fraction (Olsen-P) for a longer period in

all experimental soils as compared to sewage sludge and crop residue. From both studies, it is concluded that the addition of PM or FYM at P level 400 mg kg^{-1} is an effective approach to mobilize and render more P available for plant uptake.

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