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Phosphorus release kinetics of applied phosphate is influenced by time and organic sources in clay loam and sandy clay loam soils

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Abstract

Adsorption and precipitation are major mechanisms that play an imperative role in immobilization of phosphorus (P) in various texture soils thus limiting the crop yields. Soil organic matter (SOM) can improve P bioavailability by decreasing its sorption in soils. The aim of current experiment was to investigate best organic source to reduce P sorption in different texture soils. Press mud (PM), farmyard manure (FYM), processed city waste (CW) and poultry litter (PL) were used to examine P availability in clay loam and sandy clay loam soils. Organic sources were added at the rate of 10 t ha^{-1} according to organic matter content in clay pots having 10 kg soil capacity. Phosphorus was added at the rate of 200 mg P kg^{-1} soil by using KH_2PO_4 and moisture was maintained at 60% water holding capacity. Results showed higher adsorption of P (122 mg kg^{-1}) in clay loam soil as compared to the sandy clay loam (132 mg kg^{-1}) soil. The Olsen P influenced by organic amendments was in the order of CW > PL > FYM > PM > control. There was a significant correlation between P released by organic sources with time and soil texture. It is concluded that application of CW is best regarding P release in different texture soils.

Keywords: Phosphorus availability, sorption, manures, soil textures

Introduction

Phosphorus (P) is one of abundant elements in soil that is essential macronutrient for developmental processes and growth of agricultural crops after nitrogen (Withers *et al.,* 2008; Zhuo *et al.,* 2009a; Sharma *et al.,* 2013). Approximately 2/3 of inorganic P and 1/3 of organic P is not available in the soil, especially in soils with variable charges (Yu *et al.,* 2013). As P mobility is very low in the soil as compared to other nutrients, therefore, its use during crop growth is very low (McBeath *et al.,* 2005). About 80-90% soils in arid and semiarid regions are deficient in available P in all over the world (Memon *et al.,* 1992; NFDC, 2001). Pakistani agricultural soils are generally alkaline in pH and calcareous in nature with low level of organic matter, therefore, formation of Ca-P insoluble compound restricts P availability to plants (Sayin *et al.,* 1990; Cordell and White, 2015). Phosphates fixation with calcium (Ca) in alkaline soils (Noor *et al.,* 2017), is a major cause of its low phytoavailability (McBeath *et al.,* 2005) with markedly significant effect of soil reaction. Plant available P is an essential nutrient for optimum growth of plants (Ham *et al.,* 2018) and cannot be replaced by the intake of any other nutrient (Franz, 2008). For alleviation of P availability addition of inorganic fertilizer is becoming uneconomical and less ecologically friendly practice, because effectiveness of added P is as low as 10% (Werft and Dekkers, 1996; Wu *et al.,* 2007).

Satisfactory P availability to plants, stimulates early growth and hastens maturity in crops. Efficacious use of phosphatic fertilizers and well-organized management of P are critical components to ensure security and global food production (Cordell *et al.,* 2009). Initially manure and phosphatic fertilizers are fairly soluble and available but depends upon soil type, its availability affected with the passage of time. Combined use of organic amendments has been reported to enhance P availability in soils, provide nutrients, improve soil physio-chemical conditions and may improve the efficiency of added P fertilizers (Iyamuremye and Dick, 1996; Guppy *et al.,* 2005; Agbenin and Igbokwe, 2006; Gichangi, 2009). Poultry litter, FYM, compost, urban and industrial wastes are reported cheap and efficacious use of fertilizers to enhance agricultural productivity and soil quality. When these organic amendments are added to soil, soil health and fertility status is significantly improved that plays an imperative role regarding enhancement in the productivity of crops

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(Campbell *et al.*, 1986; Tejada *et al.*, 2006; Timilsena *et al.*, 2015).

In Pakistani agriculture sector, the availability of animal manure is quite easy comparative to other organic amendments. Manure application in soils can improve P availability by mineralization and decomposition of organic P. The acids in manures cleave Ca-P complex in alkaline pH soils (Zhuo *et al.*, 2009b; Zhang *et al.*, 2009) and causing an enhancement in available P for uptake of plants. The P adsorption capacities of soils were dependent on the type of organic amendment applied and the available soil type (Yu *et al.*, 2013). Studies have revealed that when cattle, poultry and goat manure are added to highly weathered tropical soil, P sorption efficacy in soil was reduced with an increasing period of incubation (Azeez and Averbeke, 2011).

The quality (Organic matter contents) and P releasing capacity provide good information about planning the combined use of chemical P fertilizers and organic residues (Hadas *et al.*, 2004). Besides physiological improvement in plant growth, the net effect of time in relative terms of temperature on phosphate availability depends upon adsorption or precipitation after addition of inorganic P fertilizer and time of application of organic amendment (Yusran, 2010). In arid and semi-arid regions like Pakistani, it is rarely possible to improve organic matter status of soil, rather their use to activate the process of P solubilization through the release of organic acids from added organic amendments is comparatively good approach. Moreover, soil ability to release P in soil depends on soil textural class (McDowell and Sharpley 2003).

Therefore, present study was conducted with the objective to investigate the influence of 4 different organic sources on P availability with the passage of time under two soil textural classes (sandy clay loam and clay loam).

Materials and Methods

Four organic sources, processed city waste (CW), press mud (PM), farmyard manure (FYM) and poultry litter (PL) were used in current study on clay loam and sandy clay loam textured soils to examine the sorption of P. Both sandy clay loam and clay loam textured soils were collected from research fields of Agronomy and Soil Chemistry sections in Ayub Agriculture Research Institute Faisalabad, Pakistan, respectively and was performed at Soil Chemistry Section (31.407381N, 73.048423E). The pH*s* of soil was assessed by using pH meter. The electrical conductivity (EC*e*) was assessed with a conductivity meter. For analysis of organic matter content in soil oxidation with potassium dichromate ($K_2Cr_2O_7$) followed by ferrous ammonium sulfate was used (Walkley, 1947; FAO, 1974). According to Rowell (1994) potassium in soil was determined on flame photometer. Available P in soil was analyzed by Olsen P method (Rowell, 1994). Textural classes of soil samples were determined with hydrometer method (Bouyoucos, 1962; FAO, 1974).

The organic matter of organic amendments was assessed by ignition method in a muffle furnace (Combs and Nathan, 1998). Ten kg soil was filled in pots along with organic sources @ 10 t ha^{-1} on the basis of OM content. The P was added @ 200 mg kg^{-1} using potassium dihydrogen phosphate. The pots were kept in a glass house for six months following completely randomized design (CRD) with the factorial arrangement in triplicate and moisture was maintained at 60% water holding capacity level. The soil samples were taken at 1, 10, 20, 30, 60, 120 and 180 days interval air dried before analysis, and the adsorption of P was monitored by analyzing the soil for Olsen P.

Statistical Analysis

The changes in available soil P as a function of time was estimated using power function.

$$Y = at^{b}$$

where Y is the extracted Olsen P, a is fitted value which represents the concentration of P extracted at time zero, t is the time and b is a coefficient (slop) which represents the loss in Olsen P (Y) extractability with time (X) and so has a negative value. Correlation coefficients (R^2) were obtained by least square regression of measured versus predicted values.

Statistical analysis of response data in this experiment was performed using Analysis of Variance (ANOVA) for CRD factorial and Interaction effects between Treatments × textural classes and Times of responses with textural classes were estimated using the computerized system Statistix® for Windows version 8.1 (Analytical Software ©). The difference among the treatment means was compared using the least significant difference at 5% probability level (Steel and Torrie, 1997).

Results and Discussion

The physio-chemical properties of soils used in the experiment are given in Table 1. The soils used for the study were free from salts hazards, low organic matter, marginal in available P and adequate in available K. The graphical

Table 1: Basic soil analysis

Texture	pHs	EC*e* (dS m^{-1})	Available P (mg kg^{-1})	Extractable K (mg kg^{-1})	Organic matter (%)
Clay Loam	7.78	1.25	8.02	152	0.65
Sandy clay loam	7.99	1.34	8.06	141	0.70

representation of minimum and maximum temperature regime during which the trial was conducted is shown in Figure 1.

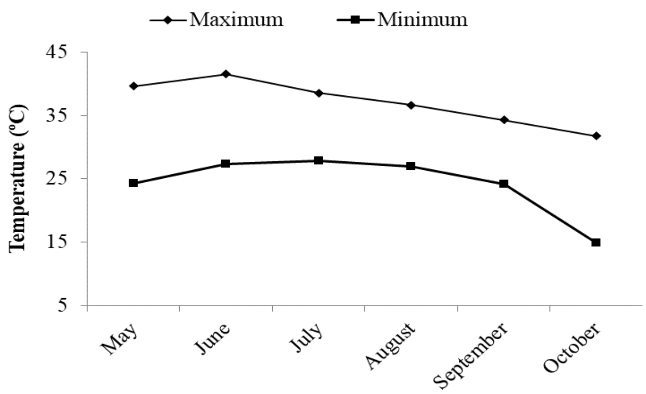

Figure 1: Temperature range in Kharif season

Results showed the P fixation of applied phosphates in both soil textural classes (Figure 2). It was observed here in controlled conditions with no organic source addition there was a decrease in P availability with time. Maximum P was fixed in early days of addition in both soil types and in later days the fixation becomes negligible. It showed there was P fixation in alkaline calcareous soil and it increased as the time of addition increased. Previous studies had also shown that with time the added P becomes fixed with Ca ions in alkaline calcareous soils (McBeath *et al.,* 2005; Noor *et al.,* 2017). It was also observed that clay loam soil adsorbed more P as compared to the sandy clay loam soil in the same time but in the early days of P addition. In later days the adsorption was same as shown by trend lines and power equations by both soil types but more precise for sandy clay loam than clay loam textural class (R^2= 0.75, 0.68). It was also verified here that there is more presence of cations in clay loam soils as compared to sandy clay loam soil which was the reason for more fixation of P in just a single day as compared to sandy clay loam soil.

With the addition of PM, the availability of applied phosphates was affected in clay loam and sandy clay loam soils (Figure 2). It was observed with the application of PM; more P was recovered in sandy clay loam comparative to in clay loam soil in the early days of P addition (Figure 2). Application of PM affected P availability in the first 60 days of P addition in both soil textures. It was also observed that the effect of PM was levelled off in later days (120-180) of P addition where clay loam and sandy clay loam fixed the equal quantity of P irrespective of time and organic manure effect.

Same trend line was observed for the application of CW in P availability for clay loam and sandy clay loam soils with same coefficient of determination (R^2 = 0.63). The results after incubation at 60% water holding capacity indicated that more P was recovered where CW was applied as compared to PM and control (No organic amendment) (Figure 2). However, impact of CW was variable in both soil textures in the early days (30) of P addition. A gradual reduction in P recovery was noted in clay loam soil. In sandy clay loam soil in early days of P addition, there was fluctuation in P recovery. The reason for this is unknown. This may be either due to sudden temperature change in 20 to 30 days of P addition in sandy clay loam or some other reason. In later days (60-180) the impact of CW was same in both textures of soils. In sandy clay loam soil, recovery of P was better as compared to clay loam soil. In clay loam soil, approximately equal quantity of P was recovered by CW at 30 days. After 60 days of P addition, in both textured soil, greater reduction in Olsen P was noted which showed that maximum P fixation occurred in early days (Jones *et al.,* 2003).

With the application of FYM, the recovery trend of applied P was the same for both clay loam and sandy clay loam soil in same incubation periods (Figure 2). The recovery of P was high in sandy clay loam soil where FYM was applied as compared to clay loam. It was observed that the P availability with the use of FYM in sandy clay loam soil was more at day one and 60th day as compared to clay loam. In clay loam soil, from 10-30 days, P recovery was almost same as sandy clay loam soil. After 60 days of P addition, the effect of FYM was negligible in both soil types which showed that after a certain time the effect of organic sources is vanished. This decreased organic matter effect may be due to temperature regime in these days of samplings. In Pakistan due to high temperatures, organic matter contents decrease with time so is their effect on P availability. This is also reported by Bramely and Barrow (1992) that increase in temperature also enhances rate of reaction between added P and soil (Silveira and O'Connor, 2013) resulting in a rapid reduction of soluble P. This needs more studies to find the exact reasons.

Figure 2 showed the recovery of P in sandy clay loam and clay loam soils by PL. It was noted that in clay loam after 30 days, P recovery was similar to P recovery in earlier 20 days. In sandy clay loam, a greater reduction in P recovery was noted after 30 days comparative to early days. Here again, least effect of organic sources was noted in later days (60-180 days) of P addition in both textured soils, which gradually showed decline to a level where no more influence of organic sources was noted.

Figure 2 showed the effect of 4 (four) organic sources on the recovery of P from clay loam and sandy clay loam soil. It was observed that all organic sources have an

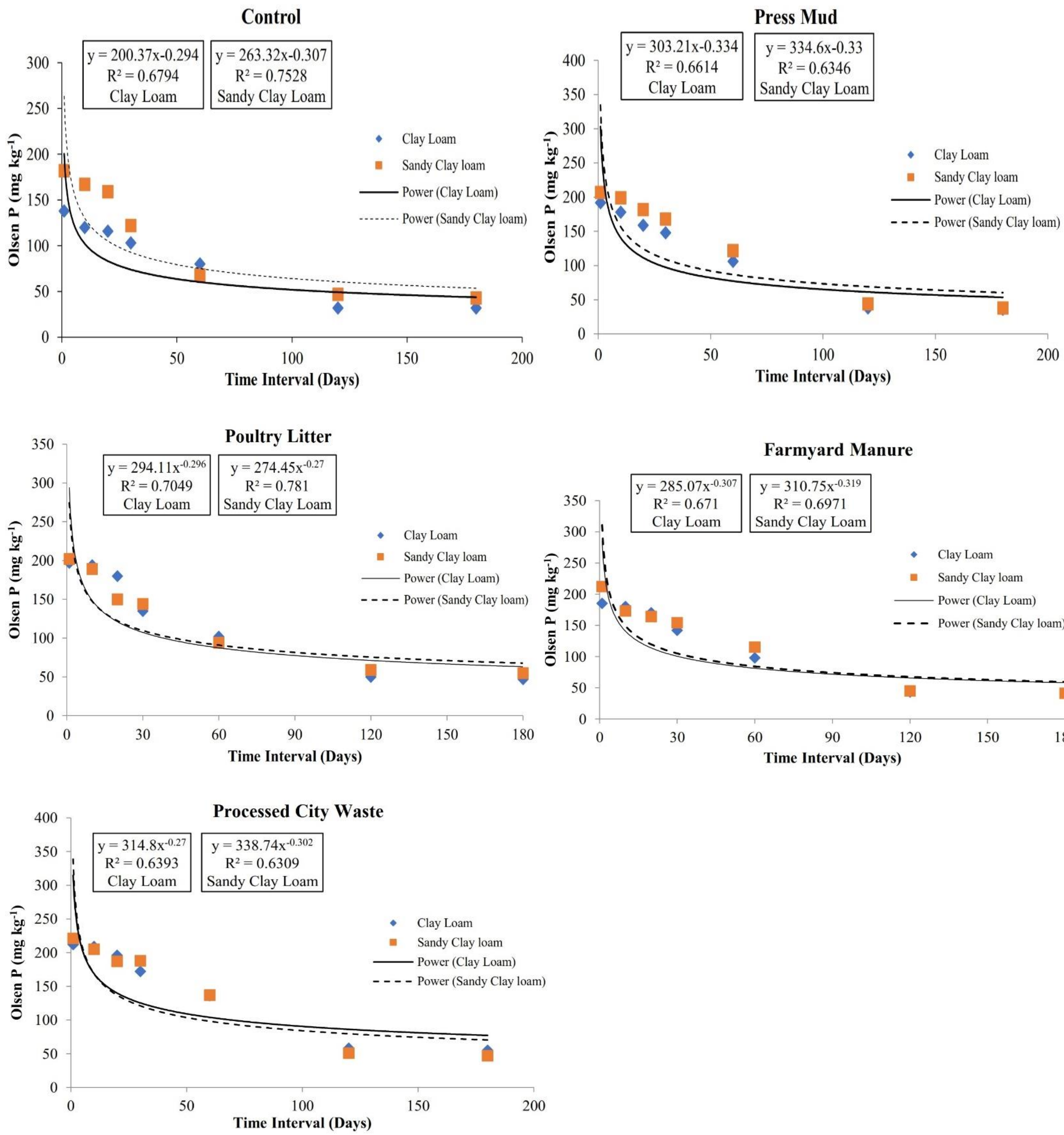

Figure 2: Olsen P recovered (power model; Y = at $^{-b}$) in two soil textural classes by application of various organic sources

influence on P recovery with time, > control; comparative to control in both textured soils. Effect of organic amendments was also reported by Garg and Bahl (2008). They suggested that the increase in P with use of organic sources as compared to control may also be attributed to the release of appreciable quantities of CO_2 during organic matter decomposition. Badanur *et al.* (1990) reported that a significant increase in available P with crop residue and green manure incorporation may be due to the release of organic acids during decomposition which in turn help in

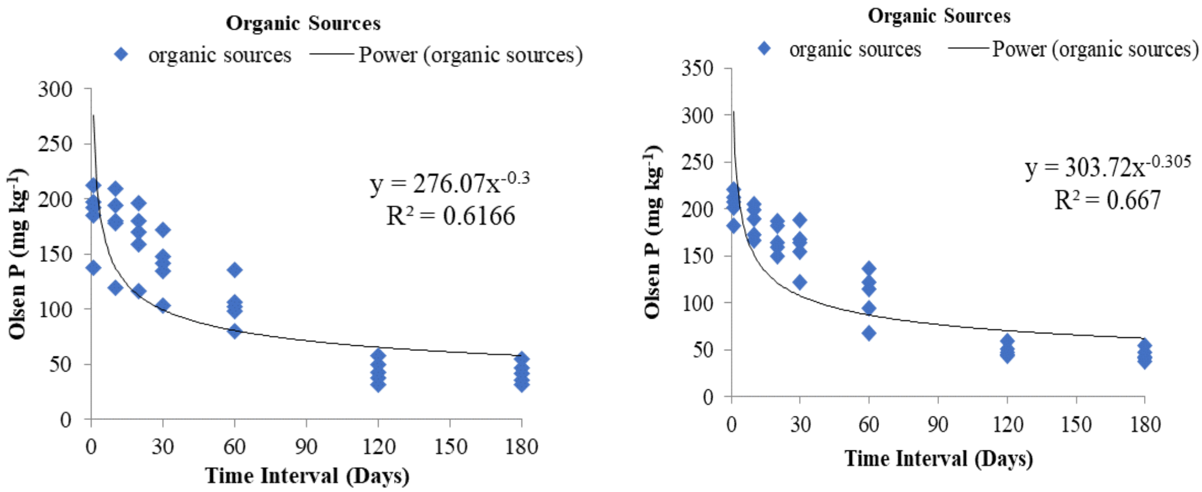

Figure 3: Olsen P recovered (power model; $Y = at^{-b}$) in two soil textural classes by application of various organic sources

releasing P by solubilizing natively present P. There were also evidences that naturally occurring organic matter in soil influence soil chemical and biological processes and enhance the P availability (Schefe *et al.*, 2009). This may be due to the presence of organic acids like humic acid or fulvic acid in organic matter which may reduce phosphates adsorption through blockage of reactive sites of minerals and increase P availability (Antelo *et al.*, 2007). It was observed that as the time of incubation increased P recovery was decreased in both types of soils even with the use of organic sources, and at a certain level of time, P recovery was levelled off in all the treatments and in control. It was observed in clay loam soil that less P was recovered as compared to sandy clay loam soil which may be due to the presence of more cations in clay loam soil as compared to sandy clay loam. In both soils, it was observed that CW was found the best among all the organic sources at all days of incubation, but its effect also vanished at 120 to 180 days of P addition. It was also observed that PL was the 2nd best organic source next to CW in both soil types but in sandy clay loam soil, its effect at 30 days was less as compared to all other organic sources. The reason for this is still unknown.

Figure 3 showed the trend line created (power equation) for all organic sources and no organic source used, at all times of incubation, for clay loam and sandy clay loam soil. Addition of organic sources reduced P sorption in both soil types, but it is more in light textured soil than in medium textured soil. From this figure, it was observed that organic sources have a greater effect on P sorption for both soil types as compared to control where no organic source was applied. An inverse positive correlation was observed between the time of incubation and P availability ($R^2 = 0.62$, 0.67) for clay loam and sandy clay loam soils, respectively, for all the organic sources and no organic matter addition. Hue *et al.* (1994) and Iyamuremye *et al.* (1996) have also reported that the addition of organic amendments can significantly decrease phosphate adsorption capacity of the soil and increase its bioavailability (Möller, 2018). It was found that in the early days (1,10, 20, 30) of incubation time the decrease in P availability was fast and slow in later days (60, 120, 180). Jalali (2009) reported that all soils showed a significant decrease in P in the early hours of addition. He also reported the decrease in P was initially rapid and became slower in later days. The change in P availability became negligible in last days. These results are also in line with our findings where the level of available P was decreased with the time of incubation and in last days change in P availability was levelled off. These results were also supported by Yusran (2010).

The P adsorption was more in clay loam soil as compared to sandy clay loam soil as there were more cations and adsorption sites present in clay loam soil. The decrease in P sorption may be due to P derived from organic sources to sorption sites occupying the sites or it may be due to blockage of sorption sites by organic matter. Decreasing of P adsorption due to organic sources might be due to less adsorption on P on soil compared to organic material (Ma and Xu, 2010).

The parameter *a* which represents the concentration of P released from soil at time zero varies in clay loam and sandy clay loam soil and organic sources. The Olsen P (mg kg^{-1}) for the organically amended soils were in the order of CW>PM>FYM>PL. This parameter of power equation in sandy clay loam soil was higher in control and organic amendments except for PL, as compared to clay loam soil. It was correlated with soil textural class as shown from control (where no organic source was added) where more P was available in sandy clay loam soil than clay loam soil. The constant *b* in power equation defines the unit change in Olsen P for a unit change in time and used to compare sandy clay loam and clay loam soil and organic amendments effect. The rate of P availability changes in different organic sources and soil types but in a narrow line. The rate of change was more in sandy clay loam soil as compared to clay loam. With the use of PM, the rate of change of available P was similar in clay loam and sandy clay loam soil but highest than all other organic sources. FYM was the 2nd next to PM, followed by CW and PL. This was also observed that change in available P with time was more in sandy clay loam soil than clay loam soil. Rapid rate of change in available P in soil is not desirable because the mineralized P is not subject to losses in soil (Jalali, 2009).

Conclusions

It is concluded that phosphorus availability is less in clay loam soil as compared to sandy clay loam soil. Organic amendments can affect P adsorption more in early days compared to later days. City waste is more effective and an economical amendment for reducing P fixation in clay loam soil and sandy clay loam soils. However, more investigation is yet suggested on use of combined application of different organic sources to improve P availability for the crop.

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