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PHOSPHORUS SORPTION CHARACTERISTICS OF FOUR SOIL SERIES

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ABSTRACT

A study was undertaken in order to find out the effect of incubation periods of phosphorus applied in soil samples of four series i.e. Gishkori, Buzdar, Sultanpur and Tikken with varying clay contents of 52, 48, 21 and 20% collected from Dera Ismail Khan, Khyber Pakhtunkhuwa, Pakistan. Soil samples were equilibrated in 20 ml aliquot of 0.01M $CaCl_2$ solution containing 0, 20, 40, 60, 80, 100, 120 and 140µg mL^{-1} of P as KH_2PO_4. The samples were incubated at room temperature, shaked twice a day for 30 minutes for 2, 8, 16 days and centrifuged at 10,000 rpm. The Gishkori soil series with the highest clay content adsorbed highest quantity of phosphate followed by Tikken that adsorbed the least as contained 20% clay content. For varying equilibration periods, maximum sorption took place in first two days after which little absorption was observed. The study showed that Gishkori soil needed more P addition than other soil samples for plant growth. Beckwith plots showed greater slopes for Gishkori and Buzdar soils indicating more phosphate buffering capacities which would replenish the nutrient if solution is exhausted. While, their intercepts were small at zero phosphate sorption hence solution might contain less P for plant growth.

Kew words: Phosphorus use efficiency, incubation, clay content, soil series, Dera Ismail Khan, Pakistan.

INTRODUCTION

Phosphorus is one of the three major plant nutrients absorbed from the soil. It is necessary for seed formation, cell division, flowering and fruiting, root development, strengthening straw and making plants resistance to diseases (Ayub *et al.,* 2002). It is a constituent of the vehicle responsible for energy transformation in the cells of both plants and animals; as such it is necessary for normal transformation of carbohydrates in plants, the changing of starches to sugar (Niamatullah *et al.,* 2011). As a component of DNA and RNA it contributes to the genetic character of biological matter. It is a constituent of certain lipids, which are helpful in the maintenance of cell membrane (Masood *et al.,* 2011).

The phosphorus contents of plant tissue are commonly ranging between 0.1 and 0.4 percent on a dry weight basis (Grant *et al.,* 2004). Phosphorus tends to concentrate in the regions of most active growth in plants. For most soil and plant conditions the phosphorus supply can be broken down into four primary factors; capacity, diffusion, kinetic and intensity (Chaudhry *et al.,* 2003). The form in which phosphorus is available in the soil to be taken up by the plant root system depends on the degree of dissociation of phosphate ions. All crops take up H_2PO_4 more readily than HPO_4 ion, and above pH 7 the relative concentrations of the divalent is greater that of monovalent ion (Alam *et al.,* 1994). Phosphorus deficiency in plants exhibits a key restraint to agricultural production system (Palomo *et al.,* 2006).

In most of the cases, soils are not deficient in total phosphorus but the available phosphorus may not be sufficient to cater for the crops due to reactions with soil particles and calcium compounds results in its less available forms in soil (Sharif *et al.,* 2000). Thus there is need of addition of phosphorus in the soil. However, the requirement assessment is baffling one and requires attention. In order to avoid wasteful practices, phosphorus fertilizer requirements should be assessed as accurately as possible (Chaudhry *et al.,* 2003). Recommendations for phosphate fertilization must take into account not only the available phosphate levels but also the phosphate sorption characteristics of soil (Tsado *et al.,* 2012). Phosphorus fertilizer requirements vary not only with the plant species but also with the buffering capacity of the soil (Sarfaraz *et al.,* 2008). The value selected is important because if it is too high, more fertilizer than required will have to be applied.

The soils of Pakistan are alkaline (pH>7.0) in reaction and mostly calcareous ($CaCO_3$) in nature (NFDC, 2003). Upon application of phosphorus fertilizer, it is utilized by the plants from soil solution and the remaining quantity may transfer to the exchange sites of clay particles where it is adsorbed or in cases is precipitated and creates trouble as clay content of soil determines the supply of phosphorus in soil (Olsen *et al.,* 1977; Sharif *et al.,* 2000; Chaudhry *et al.,* 2003; Abdu, 2013). In order to know phosphorus requirement of crops P sorption approach is used. Many workers have used this approach for phosphorus requirement under a variety of soil as well as prevailing climatic conditions (Fox 1981., Memon *et al.,* 1992; Hassan *et al.,* 1994; McDowell and

Sharpley, 2003). Besides this Phosphorus adsorption isotherms have been used by many workers to measure the phosphate adsorption capacity of soils (Mehdi *et al.*, 2007; Khan *et al.*, 2010; Khan *et al.*, 2012). Phosphate sorption capacity is an important soil characteristic that affects the plant response to phosphate fertilizer application and the downward movement of applied phosphate in soil. Fox and kamprath (1970) used the slope of adsorption isotherm of P by soil as it is directly proportional to the buffering capacity of the soil and intercept at zero adsorption of soil phosphorus solution. Plants vary in response to phosphorus; the critical levels differ for different plants. On the other hand, Beckwith (1965) suggested an adequate concentration of 0.2 mg P L^{-1} for many plants.

Keeping in view the importance of Phosphorus role in soil system, an investigation was designed to assess the soil adsorption capacities and phosphate adsorption isotherms of four soil series of D. I. Khan, Khyber Pakhtun Khuwa, Pakistan for various incubation periods. This could help to predict the fertilizer requirements of these soils in order to get maximum economic crop production on sustainable basis.

MATERIALS AND METHODS

Soil analyses: A study was undertaken in order to find out the effect of incubation periods of phosphorus applied in soil samples of four series collected from Dera Ismail Khan, Khyber Pakhtunkhuwa, Pakistan. The soil samples were taken at depth of 0-30 cm with the help of soil augar. These samples were air dried, ground then passed from 2mm sieve and analyzed for different physical and chemical properties of soil. The soil texture was determined by hydrometer method, soil reaction (pH) from the saturated soil paste, electrical conductivity (EC_e dS m^{-1}) from its saturation extract and total calcium carbonate ($CaCO_3$) by titration method of USDA Handbook 60 (U.S. Salinity Laboratory Staff, 1954). While, organic matter (%) was analyzed by Walkely and Black method (1934).

Soil sampling sites: Soils were attributed to soil series using the Maps and Memories of Reconnaissance Soil Survey of Dera Ismail Khan of the Directorate of Soil Survey, Soil Survey Staff (1969), West Pakistan.

Tikkin: The location is seven kilometers along D.I. Khan and Bannu road. The soils of the series are deep and very deep, moderately well drained, calcareous and medium textured. It has a brown/ dark brown, friable moderately calcareous and massive loam top soil.

Gishkori: The location of the soil sample is forty four kilometers south of D.I. Khan along the D.G. Khan road. The soils are very deep, well drained, calcareous and moderately fine textured. The top soil is brown, firm, massive, calcareous and of silty clay texture.

Buzdar: The location of this soil series is Mile post 31 along the D.I. Khan - D.G. Khan road. This consists of very deep, moderately well drained calcareous, saline alkali, fine textured soils.

Sultanpur: The site is situated at RD.56 along Kot Hafiz distributory. The soils of the series are deep, well drained, calcareous, medium textured. It has dark grayish brown, friable, calcareous, massive and silt loam top soil.

Phosphorus sorption studies: Two grams soil in triplicate was transferred into 30ml centrifuge tubes. Soil samples were equilibrated in 20ml aliquot of 0.01M $CaCl_2$ solution containing 0, 20, 40, 60, 80, 100, 120 and 140µg mL^{-1} of P as KH_2PO_4. Two drops of toluene ($C_6H_5CH_3$) were added to check the microbial activity. The soil samples were then incubated at room temperature and shaken twice a day for 30 minutes for 2, 8 and 16 days. At the end of each period each set of treatments was centrifuged at 10,000rpm and filtered through filter paper Whatman no. 42. Phosphorus content present in the supernatant solution was determined by using ascorbic acid as reducing agent (Watanabe and Olsen, 1965). The loss of phosphorus from solution was used to calculate sorbed P. Phosphorus sorption isotherms and Beckwith adsorption isotherms were prepared for these soils.

RESULTS AND DISCUSSION

The data regarding some physical and chemical characteristics of all four soil series are presented in Table 1 reveals that texture of soil varied from clay loam to sandy clay loam. The samples were moderately alkaline in reaction with pH values ranged from 7.7 to 8.2, non saline and highly calcareous in nature (>10%). The organic matter content of all the soil samples were less than 01 percent and low in available phosphorus. These results are in agreement with the findings of Alam (1999) who analyzed the soil samples from different series of Dera Ismail Khan and concluded that the soils were sandy loam to clayey in texture, moderately to strongly alkaline in reaction, highly calcareous and low to medium in organic matter content.

Phosphate Adsorption Isotherms: Phosphate adsorption isotherms of four soil series were determined (Table 2 to 5). The phosphate adsorption isotherms of four soil series were find out by means of plotting the equilibrium concentrations of phosphate against the amount of phosphate adsorbed. The phosphate adsorption in various soils differed (Table 6) and major portion of phosphate (797µg g^{-1}) was sorbed in Gishkori followed by Buzdar and Sultanpur soil series with values of 778 and 188µg g^{-1}, respectively. While, minimum value of 186µg g^{-1} was recorded in Tikken soil. Phosphate adsorption characteristics of soil is primarily dependent upon factors such as clay mineralogy, calcium carbonate content, soil texture, soil reaction and presence of soluble calcium in soil. The surface area of soil particles may also affect phosphate adsorption. The adsorption isotherms are result of differences in physic-chemical properties i.e. soil reaction, soil pH, amount and nature of clay content and presence of organic matter (Sarfaraz *et al.,* 2009; Khan *et al.,* 2012; and Tsado *et al.,* 2012). The soils of Pakistan being alkaline and calcareous in nature readily adsorb and convert applied phosphorus into non available calcium phosphate (Chaudhry, 1982)

Table 1. Physico-chemical characteristics of selected soil series.

Soil Series	Location	pH	ECe 10^{-3}	$CaCO_3$ %	Organic matter%
Gishkori	44 Km South of D.I.Khan along the D.G.Khan Road	7.9	3.20	15.25	0.22
Buzdar	Milepost 31 along the D.I.Khan-D.G.Khan Road	8.2	2.00	17.00	0.26
Sultanpur	R.D.56 along the Kot Hafiz Distributory	7.7	3.80	10.50	0.42
Tikken	7 Km North of D.I.Khan along the Bannu Road	8.1	1.45	14.00	0.35
Soil Series	Textural separates (%)				
	Clay		Silt		Sand
Gishkori	52		36		12
Buzdar	48		45		7
Sultanpur	21		32		47
Tikken	20		19		61

Table 2. Adsorption of phosphate (µg/g) by Gishkori soil series for different incubation periods.

Phosphate a pplied (µg/g)	Total P applied (µg/20 ml)	2-days		8-days		16-days	
		Equilibrium concentration (µg/ml)	Phosphate Sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)
0	**0**	0.0	0	0.0	0	0.0	0
20	**400**	9.2	108	8.1	119	7.7	123
40	**800**	16.1	239	13.2	268	12.7	273
60	**1200**	24.5	355	21.6	384	20.0	400
80	**1600**	35.5	445	32.7	473	31.5	485
100	**2000**	46.1	539	44.5	555	42.6	574
120	**2400**	55.2	648	53.1	669	51.5	685
140	**2800**	63.2	768	61.1	789	60.3	797

Table 3. Adsorption of phosphate (µg/g) by Buzdar soil series for different incubation periods.

Phosphate applied (µg/ml)	Total P applied (µg/20ml)	2-days		8-days		16-days	
		Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)
0	**0**	0.0	0	0.0	0	0.0	0
20	**400**	10.1	99	8.5	115	7.8	122
40	**800**	17.2	228	12.1	279	11.0	290
60	**1200**	26.6	334	24.2	358	23.4	366
80	**1600**	38.0	420	35.7	443	35.3	447
100	**2000**	49.7	503	37.3	527	36.2	638
120	**2400**	56.4	638	54.3	657	53.2	668
140	**2800**	65.4	746	63.4	766	62.2	778

Table 4. Adsorption of phosphate (µg/g) by Sultanpur soil series for different incubation periods.

Phosphate applied (µg/ml)	Total P applied (µg/20ml)	2-days		8-days		16-days	
		Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)
0	**0**	0.0	0	0.0	0	0.0	0
20	**400**	14.4	56	14.1	59	13.9	61
40	**800**	31.0	90	30.4	96	29.8	102
60	**1200**	48.6	114	47.6	124	46.8	132
80	**1600**	66.8	131	66.5	135	66.0	140
100	**2000**	85.5	145	84.9	151	83.8	162
120	**2400**	105.0	150	104.4	156	102.8	172
140	**2800**	123.0	170	122.0	180	121.2	188

Table 5. Adsorption of phosphate (µg/g) by Tikken soil series for different incubation periods.

Phosphate applied (µg/ml)	Total P applied (µg/20 ml)	2-days		8-days		16-days	
		Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)	Equilibrium concentration (µg/ml)	Phosphate sorbed (µg/g)
0	**0**	0	0	0.0	0.0	0.0	0
20	**400**	14.5	55	14.2	58	14.0	60
40	**800**	31.1	89	30.5	95	29.8	102
60	**1200**	48.7	113	47.7	123	46.2	138
80	**1600**	66.8	132	65.9	141	65.0	150
100	**2000**	85.6	144	84.9	151	83.8	162
120	**2400**	104.4	156	103.6	164	102.8	172
140	**2800**	122.8	172	122.5	175	121.4	186

Table 6. The maximum adsorbed P by four soil series.

Soil Series	Maximum P adsorbed (µg g^{-1})
Gishkori	797.00
Buzdar	777.00
Sultanpur	188.00
Tikken	186.00

The findings of the present study show that total adsorbed phosphate vary among the soils and is directly correlated to total surface area and with soil clay content (Fox and Kamprath, 1970; Rashid and Rowell 1988). It could also be seen from the present data that phosphate sorption was related to clay content of the soil and its texture. For example, Gishkori soil series with clay content of (52%) adsorbed the highest quantity of phosphate (797µg g^{-1}) at an equilibrium concentration of 60.3 and 123.0µg g^{-1} when the equilibrium concentration was 7.7µg mL^{-1}. Minimum phosphate adsorption of 186µg g^{-1} for the same treatments was recorded in Tikken soil series with 20% clay at equilibrium concentration of 121.4µg mL^{-1} and 60µg g^{-1} at equilibrium concentration of 14.0µg mL^{-1}. In both the cases total phosphate applied were 400µg and 2800µg in 20ml of 0.01M $CaCl_2$ solution. While, other values ranged between these adsorption concentrations varied with the differences in clay content of the soils. Original phosphate concentrations of the various soil values were minor as calcium presence as $CaCO_3$ might have affected phosphate adsorption negligibly (Bertrand *et al.*, 2003).

During the study clay mineralogy of the soils was not studied as it is well known that majority of the soils of Pakistan contain montmorillonite and kaolinite in various proportions and the effect could not be quantized. However, it is evident from the data that soils of Pakistan may not have that much strong P fixing capacity as usually visualized.

Effect of incubation period: All soil samples of four series were incubated for 2, 8 and 16 days during the entire period of study. The results regarding effect of duration of incubation are presented here.

Gishkori soil: At the level of 20µg g^{-1}, 108µg g^{-1} of phosphate sorbed in two days of incubation. While, at initial phosphorus level of 140µg g^{-1} phosphate sorption was reached at its maximum 85.93% for the same period of incubation. A little increase of 3.63% in amount of phosphate sorbed was noted when the soil was incubated for maximum period of sixteen days at 140µg g^{-1} level. Maximum adsorption took place for the first two days of incubation, after which a little absorption was observed. This could be owing to the fact that maximum contact occurred during the first two days. However, a little adsorption was recorded during an increase in contact period. The rate of phosphate sorption become fast earlier then it remains slow (Jalali and Zinli, 2011). While, Khan *et al.*, (2012) concluded about the highest value for phosphorus adsorption might be due to clay lattice.

Buzdar soil: During incubation period of two days Buzdar soil sorbed phosphate @ 99.0µg g^{-1} for an initial phosphorus level of 20µg g^{-1} while, phosphate sorption reached at 746µg g^{-1} (86.73%) for the same period of incubation when initial phosphorus level was increased up to 140µg g^{-1}. When incubation period was increased for eight and sixteen days, soil adsorbed 115,122 and 766, 778 at initial level of 140µg g^{-1} respectively with an increase of 6.08% and 1.56% only. An increase in incubation or contact period resulted in little adsorption. The findings of Saha *et al.,* (2004) are in favour of results obtained during the study who reported that release of phosphorus depended on the heterogeneity of the adsorption sites.

Sultanpur soil: When Sultanpur soil was incubated for two, eight and sixteen days it sorbed 56, 59 and 61µg g^{-1} (5.35%, 3.38%) respectively at initial phosphate level of 20µg g^{-1}. While, during an increase in initial phosphate level @ of 140µg g^{-1} the soil adsorbed 170, 180 and 188µg g^{-1} phosphate for the period of two, eight and sixteen incubation days respectively. An increase of 5.88 and 4.44% in phosphate adsorption was obtained when soil remained in contact with applied phosphate for eight and sixteen days of incubation. The findings of the present study are supported with those of Zhang *et al.*, (2005) who reported a significant correlation between clay content and phosphorus sorption capacity of soil.

Tikken soil: At level of 20µg g^{-1}, 55µg g^{-1} of phosphate sorbed in soil incubated for two days only. While, at initial phosphorus level of 140µg g^{-1} phosphate sorption was reached at its maximum (172µg g^{-1}) for the same period of incubation. At maximum period of sixteen days for 140µg g^{-1}, 186µg g^{-1} phosphate was sorbed which constituted an increase of 6.28% than the soil incubation period of eight days. The results showed that at all initial phosphorus levels, Tikken soil adsorbed less phosphorus as compared to other three soils. This might be due to less clay content of the soil. These results are in agreement with the findings of Mahmood *et al.*, (2000), who reported that phosphate adsorption was significantly correlated with clay content of the soil.

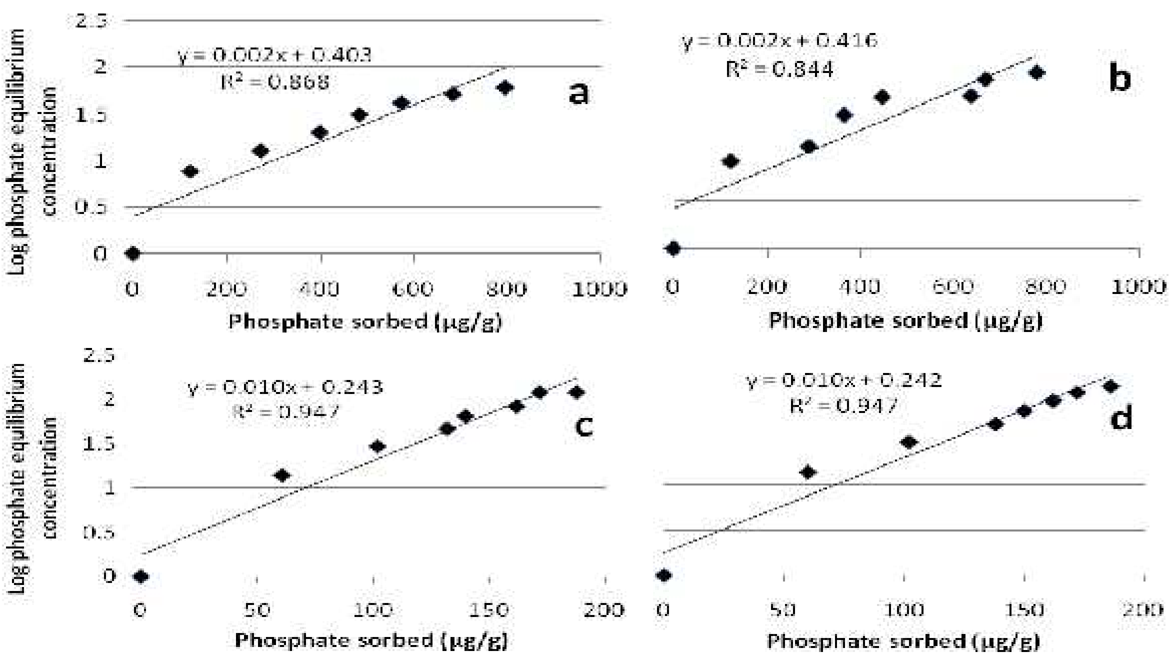

Figure 1: Beckwith plot of four soil series for 16-days equilibrium period. (a) Gishkori (b) Buzdar (c) Sultanpur (d) Tikken.

Phosphate sorption graphs: Phosphate sorption graphs were also prepared according to Beckwith plot and are presented in Fig 1. Wherein phosphate sorbed was plotted against the log of equilibrium concentration. The graph indicated that soil with higher clay contents adsorbed more phosphate per gram and thus higher slopes were obtained whereas soil with low clay contents gave lower slopes. The slope is indicative of buffering capacity of a soil (Muralidharan *et al.*, 1999). Fox and Kamprath (1970) recorded similar results.

The intercepts are however; lower for the soils with higher clay content and vice versa. Beckwith (1965) proposed that intercept at zero phosphate adsorption level could give good relationship with the soluble soil phosphate. Hence soils with low clay contents may give more soluble phosphate if the same quantity is applied to soils with high clay contents.

Conclusions: It is concluded from the results which showed that soils that contained higher amount of clay adsorbed more phosphate and had need of additional phosphorus application than low clay content soils.

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