Soil Properties Related to Phosphorus Sorption as Described by Modified Freundlich Equation in Some Soils

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ABSTRACT

Laboratory studies were conducted to investigate P sorption by a Vertisols(Kotli series), two Alfisols (Gujranwala series and Pindorian series) and two Entisols (Shahdara series and Rajar Series). All the five soils had alluvial parent material except loess derived Rajar series. The soils were characterized for their texture, organic matter, $CaCO_3$, pH, EC_e, Cation exchangeable capacity (CEC) and Olsen-P. The amount of clay in the five soils correlated significantly with their CEC, Fe, organic matter and Olsen-P. Organic matter had significant positive correlation with CEC, Fe and Olsen-P. Olsen-P was also correlated with Fe and EC_e. Calcium carbonate was significantly related to EC_e. Varying amounts of P (1,2,5 10 and 25 µg P ml^{-1}) were allowed to react with five soils for 1, 5 and 10 days. Concentration of added P and the time of reaction had a strong interactive effect on P sorption by the five soils. Maximum P was sorbed in most cases 10 days after reaction. P sorption was related to clay, CEC, Fe and soil pH. There was an indication of slow and fast reaction of P with soil constituent properties which needs further investigation.

Key Words: Soil properties; Phosphorus sorption; Freundlich equation

INTRODUCTION

There is a wide-spread phosphorus (P) deficiency in various agronomic crops grown on alkaline calcareous soils of Pakistan (Malik *et al.*, 1990). Phosphorus deficiency in crop plants can have dramatic effect on their growth and crop yields. Therefore, various chemical fertilizers are applied to such soils to realize economic crop yields by avoiding P deficiencies. But several soil, plant and climatic factors influence soil P requirement for supporting normal crop growth. The applied fertilizer P participates in several precipitation-dissolution and adsorption-desorption reactions controlling P in soil solution bathing the plant roots (Frossard *et al.*, 1995). Different soil constituents, including clay, organic matter, $CaCO_3$, Fe-oxides and Al-oxides are involved in these reactions. For example sorption of P increases as the clay content increases, particularly if Fe and Al oxides in clay are amorphous. However, a few studies conducted on the effect of $CaCO_3$ and Fe-oxides on P availability in calcareous soils have yielded somewhat conflicting results (Freeman & Rowell, 1981; Castro & Torrent, 1995). The role of properties of various soil constituents on soil P dynamics have been studied extensively for the temperate region soils. High P sorption is considered as a constraint to economic utilization of P as > 80% of fertilizer applied P will be immediately unavailable for plant uptake either due to adsorption, precipitation or both in a soil (White, 1982). No significant information is available regarding soil properties important of P adsorption in relatively young alkaline calcareous soils of Pakistan. A preliminary study was, therefore, initiated to identify soil properties important for P sorption in such soils.

MATERIALS AND METHODS

Soils. Representative surface (0-15 cm) soil samples were collected for Gujranwala series (Udic Haplustalf), Kotli series (Entic Chromustert), Pindorian series (Udic Haplustalf), Rajar series (Typic Ustorthent) and Shahdara series (Typic Torrifluvent). The samples were air-dried and ground to pass through a 2 mm sieve. They were characterized for various physico-chemical properties reported in Table I. The soils were analyzed for texture by hydrometer (Day, 1965), for $CaCO_3$ by the acid dissolution method (Allison & Moodie, 1965) and for organic matter by the Walkley-Black method (Allison, 1965). Soil pH was measured in soil saturated paste and soluble salts (EC_e) were determined in soil saturated paste extract.

Sorption study. Sorption study was conducted in an incubation experiment in which one gram portion of each soil was mixed with 10 mL solution of KH_2PO_4 prepared in 0.01 M $CaCl_2$ containing 1, 2, 5, 10 and 25 µg P mL^{-1} solution in centrifuge tubes. The supernatant was centrifuged after shaking for one hour. Similarly two more sets of centrifuge tubes were prepared and incubated for five and 10 days, respectively. Those were shaken daily for an hour. After incubation, these sets were centrifuged at 2500 rpm for five minutes. The supernatant was filtered through Whatman filter paper No. 42 for P analysis. (Watanabe & Olsen, 1965). Phosphorus adsorbed was the difference between the amount of P added to the soils and P in the filtrate. Phosphorus sorption was described by the Freundlich equation given below:

$$X = aC^b \qquad [1]$$

Where X is the amount of P sorbed, C is concentration in the equilibrium solution and a and b are constants.

RESULTS AND DISCUSSION

Soil properties. The five soils markedly varied in physical and chemical properties (Table I). All the soils, except Shahdara, had either marginal or high Olsen- P (≥5 mg P

et al., 1995; Samadi & Gilkes, 1999).

P sorption. The amount of P sorbed varied significantly among the five soils The amount of P sorbed in two representative soils is depicted in Fig. 1 as the logarithmic form of Frendulich equation. However, there was strong interactive effect of added P and equilibration time on the amount of P sorption by the five different soils. In most

Table I. Selected /Physical and chemical properties of the soils

Soil	Classification	Texture	pHs	Clay %	O.M %	CaCO₃ %	CECc mole kg⁻¹	Olsen P mg kg⁻¹	EC_e dS m⁻¹	Fe %	Clay mineral compositionᵃ
Pindorian	[Udic Haplustalf]	Loam	7.6	18	0.28	0.81	12.3	7.6	1.4	0.7	ᵇMi=3, K =2, GE=1 Vr=1
Rajar	[Typic Ustorthent]	Sandy loam	7.8	12	0.37	18	7.25	5.2	0.40	0.9	Mi=2, Vr=1, Mt=1, Kk=1
Shahdara	[Typic Torrifluvent]	Silty clay loam	8.2	17	0.32	5	10.4	3.9	0.89	0.7	Mi=2, Kk=2, Mt=1 Cl=1
Kotli	[Entic Chromustert]	Clay	7.8	55	0.80	1.50	31.5	15.0	1.3	1.2	Mt=3, Mi=3, Kk=3, Cl=1
Gujranwala	[Udic haplustalf]	Silty clay loam	7.9	20	0.25	3.8	16.5	5.0	1.1	0.70	Mi=3,Kk=2, Mt=1, Vr=1

ᵃAhmad *et al.* (1985); ᵇMi = mica; Kk=Kaolinite; Vr=Vermiculite; Mt=Montmorillonite; Cl=Chlorite; Ge=Goethite 1, 2 and 3 show relative abundance as trace, small and moderate, respectively

kg⁻¹ soil). The Shahdara series had 3.9 mg P kg⁻¹ soil. The amount of bioavailable P, initially found in the soils by 0.5 M Na HCO₃ extraction (Olsen-P) was significantly related to the amount of clay, organic matter content, cation exchange capacity (CEC) and Fe content of the five soils (Table III). These soils were low in organic matter (<1%). The amount of clay in the five soils significantly correlated with their CEC, organic matter and Fe content (Table III). The soils were non-saline (EC_e < 4 dS m⁻¹) and alkaline in reaction having variable content of free CaCO₃. The Fe extracted by citrate-bicarbonate did not vary much among the five soils. It is present mostly on ped surfaces relatively in small amounts in alkaline calcareous soils but provides very reactive surfaces in a soil. Iron oxides have recently been found important for surface reactions of P even in calcareous soils (Holford & Mattingly, 1975; Ryan *et al*., 1985; Afif *et al*., 1993, Rahmatullah *et al*., 1994; Frossard

cases maximum P was sorbed after 10 days of equilibrium. Involving both the equilibrium period and levels of added P, sorption of P by the five soils was described by the modified Freundlich equation (Barrow & Shaw, 1975) given below:

$$X=aC^bt^d \qquad [2]$$

Fig. 1. Freundlich plot of phosphorus sorption in Kotli (O) and Shadara (●) series after five days of equilibrium period

Table III. Linear correlation coefficient among soil and phos

	A	b	d	Clay	O.M.	Fe				
b	0.11									
d	-0.83	-0.5								
Clay	0.47	0.70	-0.40							
O.M.	0.55	0.49	-0.37	0.93						
Fe	0.72	0.43	-0.45	0.84	0.97					
CEC	0.47	0.85	-0.58	0.98	0.85	0.75				
CaCO₃	0.27	-0.91	0.22	-0.48	-0.18	0.04	-0.57			
pH	-0.63	-0.16	0.78	-0.14	-0.12	-0.22	-0.16	0.08		
EC_e	0.47	-0.82	-0.001	-0.37	-0.06	0.18	-0.47	0.95	-0.22	
Olsen-P	0.59	0.69	-0.61	0.95	-0.92	0.86	0.91	-0.42	-0.42	-0.23

A correlation coefficient of 0.81, 0.88 and 0.96 is required for significance at p <0.1, 0.05 and 0.01, respectively

Table II. Phosphate sorption properties

Soil	Constants of Equation (2)			Total Pᵃ sorbed (mg kg⁻¹) day 5 at 0.2 mg P dm⁻³ in solution
	A	b	d	
Pindorian	4.03	0.88	0.18	1.34
Rajar	5.02	0.76	0.20	0.03
Shahdara	2.82	0.84	0.27	1.13
Kotli	5.19	0.94	0.16	1.48
Gujranwala	4.40	0.89	0.17	1.38

a calculated according to equation (2)

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Rahmatullah *et al*., 1994).

The values of constant b did not vary much among the soils (Table II). It is related to P sorption in relation to concentrations of the added P. However, it correlated significantly with amount of charge measured as CEC in the soils (Table III). It also had a negative but significant (p < 0.1) correlation with EC_e (Table III). It agrees with Hedley *et al*. (1995) who observed decreased P sorption with increasing soluble salts.

The values of constant d also varied significantly among the soils (Table II). It is related to time dependent reaction of applied P in five soils and had a non-significant correlation with CEC and pH values of the soils. Its negative correlation with CEC indicated that P sorption sites decreased with time.

On the other hand its positive correlation with pH indicated progressive P sorption with time to be a function of precipitation-dissolution reactions in soils. Such a fast and slow type of added P in calcareous soils have been indicated by others (Solis & Torrent, 1989). Those are important for P fertilizer management of soils. However, further P sorption studies are warranted involving more soils with variable properties.

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