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Phosphate sorption-desorption characteristics of some ferruginous soils (Alfisols) of eastern India

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Abstract

In view of low native phosphate concentrations in soils of the tropical India, a study on phosphate sorption and desorption in four ferruginous soils (Alfisols) of eastern India was conducted. Sorption isotherms were described by the Langmuir and the Freundlich equations. Phosphate sorption maximum was highest (682 to 889 mg kg^{-1}, mean 786) in Pathargara soils (Rhodic Kandiustalfs) followed by the Dakhalbati (Kanhaplic Haplustalfs) (157 to 686 mg kg^{-1}, mean 502) and Dumka (Kanhaplic Haplustalfs) (258 to 757 mg kg^{-1}, mean 502) series and was lowest (177 to 480 mg kg^{-1}, mean 325) in Aamjora soils (Kanhaplic Rhoudstalfs). The fraction of sorbed phosphate recovered by the extractants followed the same trend of phosphate sorbed but neither the phosphate affinity constant (K) nor the maximum phosphate buffering capacity (b.K.). Correlations between phosphate sorption parameters and selected soil properties were examined.

Additional Keywords: Phosphate sorption maximum, phosphate affinity constant, maximum phosphate buffering capacity.

Introduction

Ferruginous soils (Alfisols) are the dominant soils of the semi-arid tropics and crop yields are often limited by low native soil P concentrations. Sorption and desorption reactions have a large impact on P availability to plants and on the P losses in runoff and leaching in soil profiles. The main soil properties that influence these reactions include the amount and type of clay, amounts of iron and aluminium oxides, organic matter content, pH and calcium carbonate content (Solis and Torrent 1989 and Chand *et al.* 1995).

Though soil P sorption by Alfisols is the subject of recent studies (Kaistha *et al.* 1997) it has not been studied extensively in tropical Alfisols. The first objective of the present investigation was, therefore, to determine the ability of representative Alfisols to sorb phosphate under laboratory conditions and to compare sorption isotherms between soil series. The second objective was to determine the effects of the phosphate sorption capacity and phosphate affinity constant on the quantity of added phosphate recovered with different extractants. A final objective was to develop regression equations and to use existing soil characteristics data to predict relative phosphate sorption potentials in some Alfisols.

Materials and methods

Four soils, three of ferruginous soil (Aamjora, Pathargara and Dumka series) in Godda and Dumka districts of Bihar and one of alluvial soil (Dakhalbati series) in Birbhum district of West Bengal, India were selected for this study. The samples were air dried and passed through a 2 mm sieve for subsequent analysis. The physical and chemical properties and different forms of iron and aluminium are given in tables 1 and 2. Free Fe and Al fractions were determined by separate (not sequential) extractions with 0.2 M ammonium oxalate adjusted to pH 3; and the dithionite-citrate-bicarbonate reagent. It is generally believed that extraction by the former method removes organically bound plus inorganic amorphous (Feo, Alo), and the latter extraction removes organically bound, inorganic amorphous, and crystalline Fe (Fed, Ald) (Parfitt and Childs 1988, Borggaard 1988). Crystalline Fe is designated by Fed-Feo.

Table 1. Physical and chemical properties of the soils

Depth (cm)	pH (1:2.5)		EC (1:5) dS m^{-1}	CEC cmol(+) kg^{-1}	Organic carbon (g kg^{-1})	Particle size distribution			Texture*
	H_2O	1*M* KCl				Sand	Silt	Clay	
						%			
Aamjora series : Fine loamy mixed Kanhaplic Rhodustalfs									
0-20	8.14	7.13	0.02	6.1	1.7	77.8	7.1	15.1	ls
20-50	8.43	7.32	0.07	9.8	1.2	76.0	11.7	12.3	sl
50-87	8.34	7.24	0.01	5.7	1.1	71.8	11.2	17.0	sl
87-150+	8.43	7.36	0.01	6.0	0.6	75.2	22.9	1.9	sl
Dakhalbati series : Fine loamy mixed Kanhaplic Haplustalfs									
0-15	5.07	4.38	0.01	5.4	4.0	34.3	30.4	32.3	sil
15-28	6.74	5.48	0.03	8.1	3.3	48.1	22.4	34.5	sc
28-65	7.03	5.50	0.05	8.7	2.8	24.9	26.9	48.2	cl
65-94	7.64	6.03	0.04	8.7	2.6	51.5	16.4	32.1	cl
94-150+	8.29	7.40	0.03	6.8	2.2	42.5	27.6	29.9	cl
Pathargara series : Fine loamy mixed Rhodic Kandiustalfs									
0-14	6.22	5.28	0.07	9.9	7.7	17.8	30.2	53.0	sil
14-60+	6.26	5.29	0.08	10.4	5.7	18.7	40.6	40.7	sil
Dumka series : Fine loamy mixed Kanhaplic Haplustalfs									
0-10	5.40	4.70	0.08	10.1	11.3	38.6	24.0	37.4	cl
10-38	5.90	4.80	0.03	11.9	11.1	31.9	30.5	37.6	sil
38-50+	6.00	4.90	0.03	6.7	1.9	44.8	21.2	34.0	l

*scl=sandy clay loam; l=loam; sil = silty loam; cl = clay loam; sc = sandy clay; sl = sandy loam; ls = loamy sand

Sorption experiment

2 g soil was equilibrated for two days with 20 mL of 0.01 *M* $CaCl_2$ solution containing 0, 20, 40, 60, 80, 100, 120 and 150 mg PL^{-1} as KH_2PO_4 with one drop of toluene in inhibit microbial activity. The soil was then shaken for 30 min twice daily using a reciprocal mechanical shaker at 25°C. After equilibration, P in the supernatant was determined. The difference between P added and that estimated in the soil solution was taken as P sorbed. Phosphorus sorbed (mg kg^{-1}) and P remaining in solution (mg L^{-1}) were plotted to get the sorption isotherm. The sorption values of each soil were plotted according to the Langmuir isotherm.

$$C/(x/m) = (1/Kb) + (C/b)$$

where C is the equilibrium P concentration (mg L^{-1}), x/m is the amount of sorbed P (mg kg^{-1}), b and K are the constants related to P sorption (mg kg^{-1}) and bonding energy (L mg^{-1}), respectively. The plot of C/ (x/m) *vs.* C should give a straight line from which b^{-1} (slope) and K (slope/intercept) can be calculated.

Maximum phosphate buffering capacity of the product of a phosphate sorption capacity (or monolayer coverage in mol P kg^{-1} of soil) and a phosphate affinity constant are related to the binding strength (Dalal and Hallsworth 1976), regulating the partition of phosphate between solution and solid phase.

Table 2. Extractable iron and aluminium oxides of the soils

Depth (cm)	Extractable Fe_2O_3		Extractable Al_2O_3		Crystalline Fe_2O_3
	Feo*	Fed	Alo	Ald	
	Aamjora series : Fine loamy mixed Kanhaplic Rhodustalfs				
0-20	0.30	0.33	0.28	0.38	0.03
20-50	0.63	0.71	0.70	0.71	0.08
50-87	0.28	0.31	0.18	0.31	0.03
87-150+	0.30	0.33	0.27	0.35	0.03
	Dakhalbati series : Fine loamy mixed Kanhaplic Haplustalfs				
0-15	0.24	0.28	0.15	0.19	0.04
15-28	0.55	0.60	0.47	0.56	0.05
28-65	0.61	0.69	0.61	0.64	0.08
65-94	0.60	0.68	0.57	0.60	0.08
94-150+	0.40	0.41	0.43	0.54	0.01
	Pathargara series : Fine loamy mixed Rhodic Kandiustalfs				
0-14	0.64	0.72	0.76	0.89	0.08
14-60+	0.74	0.82	1.05	1.16	0.08
	Dumka series : Fine loamy mixed Kanhaplic Haplustalfs				
0-10	0.70	0.79	0.96	1.11	0.09
10-38	0.80	0.90	1.20	1.84	0.10
38-50+	0.33	0.38	0.32	0.43	0.05

*Feo, Alo = acid NH_4 - oxalate extractable iron and aluminium respectively.
Fed, Ald = sodium dithionite citrate bicarbonate extractable iron and aluminium respectively.

The Freundlich equation takes the form, $x/m = K^1 C^1/n$,where x/m is the phosphorus sorption in mg kg^{-1} of soil, C is the equilibrium concentration in mg L^{-1}, K^1 and n are two constants.

Desorption experiment

The soil from the sorption run (after the supernatant liquid was decanted off) was washed with alcohol to make the soil free from soluble P. The washed soil was stirred continuously with 40 mL extractants for 5 minutes and then centrifuged. The extractants used depending on soil pH were Bray's No. 1 for pH <5.5, Bray's No. 2 for pH $5.5 \leq$ pH $5.5 \leq 6.5$ and Olsen's for pH >6.5. Desorption experiments were conducted at 25°C. The amount and percentage of phosphorus desorbed were then calculated.

Results and discussion

Sorption characteristics

Phosphate sorption in soil increased with increasing levels of P added to soil. At a given level of added P, P sorption had no regular trend with depth. The results indicated that mean sorbed phosphate was highest in Pathargara series followed by Dumka, Dakhalbati and Aamjora soils at all concentrations except at 20 and 40 mg kg^{-1} of added P where Dumka soils sorbed higher amount of phosphate compared to Pathargara soils. The high phosphate sorption capacity of Pathargara soils can be attributed to the overall effect of enormous specific surfaces of highly reactive clay, Feo, Alo and Fed content.

Langmuir sorption isotherm

The sorption of soils, plotted as C vs C/(x/m), gave linear line according to the Langmuir equation. The P sorbed at high energy surface (b) varied from 157 to 889 mg kg^{-1} with an average of 529 mg kg^{-1} and the bonding energy (K) was between 0.011 and 0.106 L mg^{-1} with an average of 0.028 L mg^{-1} (Table 3). Sorption maximum (b) expressed as mg kg^{-1}, was highest (682 to 889, mean 786) in Pathargara soils as was lowest (177 to 480, mean 325) in Aamjora soils. The bonding energy (K) was highest (0.011 to 0.106 L mg^{-1}, mean 0.044) in Aamjora soils and was lowest (0.012 to 0.012 L mg^{-1}, mean 0.012) in Pathargara soils).

Maximum phosphate buffering capacity

The maximum phosphate buffering capacity varied from 5.42 to 21.63, 6.70 to 11.60, 8.20 to 10.50 and 11.00 to 14.80 L kg^{-1} with mean being 10.20, 8.70, 9.40 and 12.40 L kg^{-1}, respectively, in the Aamjora, Dakhalbati, Pathargara and Dumka soils (Table 3). The buffering capacity increased with depth in Aamjora, Pathargara and Dumka soils with some minor exceptions in Aamjora and Dumka soils and decreased with depth in Dakhalbati soils. Variation in the buffering capacity within the soils is due to variation in their physical and chemical parameters (Tables 1 and 2). Buffering capacity values can be assessed from changes in P quantity and intensity produced by cropping i.e. the ratio between the change in labile P and the change in concentration of P in solution. Thus sorption isotherms can provide a rough estimate of the "field" phosphate buffering capacity in the soils studied.

Table 3. Phosphate sorption parameters of the soils

Depth (cm)	Langmuir isotherm			Freundlich isotherm	
	Sorption maxima b (mg kg^{-1})	Bonding energy K (L mg^{-1})	Maximum buffering Kb (L kg^{-1})	K^1 capacity	1/n mg kg^{-1}
	Aamjora series : Fine loamy mixed Kanhaplic Rhodustalfs				
0-20	400	0.013	5.56	12.6	0.650
20-50	480	0.011	5.42	25.1	0.680
50-87	177	0.046	8.17	14.1	0.575
87-150+	205	0.106	21.63	55.0	0.278
	Dakhalbati series : Fine loamy mixed Kanhaplic Haplustalfs				
0-15	157	0.074	11.60	13.2	0.847
15-38	646	0.013	8.34	16.0	0.714
38-65	686	0.013	8.90	12.6	0.746
65-94	571	0.014	8.10	16.0	0.714
94-150+	451	0.015	6.70	10.0	0.667
	Pathargara series : Fine loamy mixed Rhodic Kandiustalfs				
0-14	682	0.012	8.20	13.2	0.763
14-60+	889	0.012	10.50	12.0	0.813
	Dumka series : Fine loamy mixed Kanhaplic Haplustalfs				
0-10	757	0.015	11.00	31.6	0.571
10-38	491	0.030	14.80	22.4	0.662
38-50+	258	0.044	11.40	30.2	0.442

Freundlich sorption isotherm

The Freundlich's constant K^1 (as a measure of adsorbability) and n (as energies of sorption) are worked out from Freundlich sorption curve and are presented in table 3. The result indicated that coefficient K^1, expressed in mg kg^{-1} followed the sequence : Dumka - 22.4 to 31.6 (mean 28.1) > Aamjora - 12.6 to 55.0 (mean 26.7) > Dakhalbati - 10.0 to 16.0 (mean 13.6) > Pathargara - 12.0 to 13.2 (mean 12.6). The K^1 value decreased with depth in Pathargara soils but inconsistent behaviour was observed in other soils.

Desorption of sorbed phosphate

The results of the desorption of the sorbed phosphate from the soil by Bray's No. 1, Bray's No. 2 and Olsen's reagent are presented in table 4. While it increased with increasing amount of phosphate sorbed, the amount of sorbed phosphate extracted varied considerably among the soils which suggests that some additional soil factors also affect the amount desorbed by the three extracting solutions. Differences in phosphate extraction from various soils were similar for the three extractants (Table 4), because extractants were selected based on soil pH. The extractants tended to desorb more phosphate from the soils with high phosphate sorption and less from those with low phosphate sorption. Desorption of sorbed phosphate was the highest (58.8 to 481 mg kg^{-1}, mean 296) in Pathargara soils and was the least (58.5 to 216 mg kg^{-1}, mean 140) in Aamjora soils.

Table 4. Desorption of P from soils

Depth (cm)	Desorption of sorbed phosphate (mg.kg^{-1}) at different concentrations (mg PL^{-1})								Mean attainable recovery(%)
	20	40	60	80	100	120	150	Mean	
Aamjora series : Fine loamy mixed Kanhaplic Rhodustalfs									
0-20	42.8	92.6	142	167	192	191	222	150	82.0
	(57.1)*	(74.1)	(81.4)	(83.2)	(85.2)	(85.0)	(87.0)		
20-50	43.4	93.6	143	169	193	218	268	161	83.7
	(57.9)	(74.9)	(81.9)	(84.3)	(85.9)	(87.3)	(89.3)		
50-87	43.8	73.1	98.1	120	145	170	195	121	80.4
	(58.4)	(73.2)	(78.4)	(79.9)	(82.8)	(84.9)	(86.6)		
87-150+	104	128	154	158	162	177	178	126	72.5
(83.1)	(85.0)	(87.7)	(87.8)	(87.3)	(88.5)	(88.8)			
Dakhalbati series : Fine loamy mixed Kanhaplic Haplustalfs									
0-15	87.0	89.1	119	139	164	189	214	131	92.6
	(87.0)	(89.1)	(91.7)	(92.7)	(93.7)	(94.4)	(94.9)		
15-28	68.2	119	168	268	318	368	393	243	89.6
	(54.6)	(67.7)	(74.8)	(82.5)	(84.9)	(86.6)	(87.4)		
28-65	57.5	132	207	233	283	307	382	229	76.3
	(57.5)	(75.6)	(83.0)	(84.6)	(86.9)	(87.8)	(89.9)		
65-94	67.8	193	218	243	268	318	392	243	88.2
	(67.8)	(85.7)	(87.0)	(88.3)	(89.2)	(90.7)	(92.3)		
94-150+	54.0	104	154	204	229	253	279	182	89.6
	(72.0)	(83.0)	(87.0)	(90.5)	(91.4)	(92.1)	(92.8)		
Pathargara series : Fine loamy mixed Rhodic Kandiustalfs									
0-14	77.9	153	228	303	353	403	453	281.3	92.7
	(77.9)	(87.3)	(19.1)	(93.1)	(94.1)	(94.7)	(95.3)		
14-60+	39.6	184	334	335	359	409	509	310.1	88.4
	(49.4)	(82.0)	(89.2)	(89.2)	(89.9)	(91.0)	(92.6)		

Dumka series : Fine loamy mixed Kanhaplic Haplustalfs									
0-10	90.7 (72.6)	206 (85.7)	266 (88.5)	316 (90.2)	366 (91.4)	406 (92.2)	491 (93.4)	305.6	89.9
10-38	108 (86.2)	233 (83.1)	308 (94.6)	382 (95.6)	407 (95.8)	432 (96.1)	482 (96.4)	336.0	95.0
38-50+	63.4 (63.4)	113.4 (75.8)	139 (79.1)	164 (88.9)	188 (83.6)	213 (85.3)	238 (86.6)	159.8	81.4

* Figures in parenthesis indicates per cent desoprtion relative to sorbed P.

The maximum attainable recovery was worked out for each soil as the ratio of the total amount of phosphate extracted to the total amount of P sorbed. The range in per cent phosphate desorbed relative to the sorbed and mean maximum attainable recovery followed the order : Pathargara - 88.4 to 92.7% (mean 90.6%) > Dumka - 81.4 to 95.0% (mean 88.8%) > Dakhalbati - 76.3 to 92.6% (mean 87.3%) > Aamjora - 72.5 to 83.7% (mean 79.7%). The results of the present study indicated phosphate desorption to be a function of the same soil properties associated with sorption. This observation is in close agreement with the results of Mendoza and Barrow (1987).

Correlation between phosphate sorption parameters and selected soil parameters

Maximum P sorption value (b value) was associated with pH (H_2O) ($r=0.52^{*}$) (Table 5). This result is in contrast to that reported by Patiram *et al.* (1990). There was a highly negative significant correlation between sorption maximum and EC ($r= -0.78^{***}$). Cation exchange capacity was highly correlated with the sorption maximum (b) ($r=0.76^{***}$).

Table 5. Correlation coefficients among the sorption parameters of P and selected soil properties

Correlation between	Correlation coefficient	Regression equation
Sorption maxima (b)		
and pH (H_2O)	0.52^{*}	Y = 209.1 x + 100.3
and EC	-0.78^{***}	Y = -251.01 x + 802.7
and CEC	0.76^{***}	Y = 0.02 x + 80.43
and organic carbon	0.78^{***}	Y = 675.7 x + 448.6
and Alo	0.62^{*}	Y = 1.52 x + 75.22
and Ald	0.56^{*}	Y = 1.41 x + 31.0
and Feo	0.88^{***}	Y = 1.01 x + 10.23
and Fed	0.89^{***}	Y = 1.03 x + 94.3
and bonding energy (K)	-0.95^{***}	Y = -238.0 x + 852.9
Bonding energy (K)		
and EC	0.65^{**}	Y = 0.052 x + 0.0058
and CEC	-0.66^{**}	Y = -0.092 x + 0.08
and organic carbon	0.53^{*}	Y = 0.016 x + 0.003
and Alo	-0.60^{*}	Y = -0.08 x + 0.058
and Ald	-0.56^{*}	Y = -0.0061 x + 0.063
and Feo	-0.82^{***}	Y = -0.024 x + 0.072
and Fed	-0.79^{***}	Y = - 0.23 x + 0.072
and buffering capacity (Kb)	0.93^{***}	Y = 340.3 x + 1.95

Buffering capacity (Kb)		
and CEC	- 0.93***	Y = -5.31 x + 17.31
and Clay	0.63*	Y = 13.31 x + 3.75
and organic carbon	0.98***	Y = 14.42 x + 4.76
K^{1} and organic carbon	0.64*	Y = 28.7 x + 9.61
and Alo	- 0.69*	Y = -12.16 x + 462.8
and Feo	- 0.51*	Y = -3.2 x + 333.85

* Significance at 5% level (r >0.5139)
** Significance at 1% level (r >0.6411)
*** Significance at 0.1% level (r>0.7603)

The value of b was correlated significantly at 0.1% level with organic carbon (r=0.78**). A similar relationship has been reported for Sikkim soils (Patiram *et al.* 1990). However, according to Chand *et al.* (1995) although organic carbon is often related to sorption maximum, it is unlikely that P combines directly with the organic constituents, but with the associated cations particularly Fe and Al. This is confirmed by the correlation coefficient between sorption maximum and Alo (r=0.62*), Ald (r=0.56*), Feo (r=0.88***) and Fed (r=0.89***). The affinity constant (K) which reflect the bonding energy of phosphate to soil particles, negatively correlated with the phosphate sorption maximum (b) (r= -0.95***).

The value of K (bonding energy) was correlated significantly with EC (r=0.65**) and buffering capacity (Kb) (r=0.93***) in Alfisols. Since the affinity constant (K) is a component of the buffering capacity, such strong relationship may be expected. The bonding energy has significant correlation with CEC (r= -0.66**), organic carbon (r= 0.53*), Alo (r= -0.60*), Ald (r= -0.56*), Feo (r= -0.82***) and Fed (r= -0.79***).

The maximum phosphate buffering capacity (Kb), estimated from the Langmuir isotherm, is more closely correlated with organic carbon (r=0.98***) than with clay (r=0.63*), suggesting the dominant role of organic carbon in P sorption characteristics. The cation exchange capacity had only negative contribution for buffering capacity (r= -0.93***).

The soil properties, most closely correlated with K^{1}, are oxalate extractable Al (Alo) (r= -0.69**), followed by organic carbon (r=0.64**) and oxalate extractable Fe (Feo) (r= -0.51*). Oxalate soluble Fe (Feo) and Al (Alo) are correlated with K^{1}, but since they are present in very small amount (Solis and Torrent 1989), the contribution of amorphous oxides of Fe and Al is likely to be negligible. It is difficult, however, to differentiate the contribution of Fe and Al oxides extracted by ammonium oxalate to sorption from that of organic carbon because all the components are associated with each other. Although no definite cause-effect relationship can be drawn from this, the correlation coefficients are similar in magnitude to the values found from correlation coefficients for different groups of soils of the Mediterranean areas (Solis and Torrent 1989). This points out the important role of Fe and Al oxides and organic matter on P sorption.

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