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Phosphate Adsorption in Aridisols in Relation to Soil Properties

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Abstract: Six representative soils belonging to Aridisols of western Rajasthan, and differing in physico-chemical properties, were studied for P adsorption characteristics. The data followed Langmuir adsorption isotherms. Adsorption maxima (b) varied from 0.078 to 3.470 mg P per g soil and was significantly correlated with organic matter and cation exchange capacity (CEC) of the soils. However, bonding energy coefficient (K) values varied from 0.016 to 0.215 $\mu g\ ml^{-1}$ and showed no correlation with any soil property. The phosphorus buffering capacity (PBC) varied from 1.45 to 11.76 ml g^{-1} soil. Non-calcareous soils have higher PBC than calcareous soils. The per cent phosphate adsorption was found related with bonding energy. The finding suggests that P requirement of arid soils with low clay content and organic matter mainly depend on PBC and $CaCO_3$ content of the soils.

Key Words : Adsorption isotherms, soil physico-chemical characteristics, phosphorus adsorption, phosphorus buffering capacity.

Phosphorus adsorption by soils has a significant role in sustaining and building up phosphorus supplying capacities of arid zone soils. It is mainly responsible for rendering soluble phosphate in soil solution to plant-unavailable form. Adsorption isotherms have been used to investigate the nature of various types of adsorption phenomena. The main motivations for describing adsorption curves are to find out the soil characteristics responsible for P adsorption and to predict the fertilizer P need of crops in different soils (Klages *et al.*, 1988).

The P adsorption characteristics are mainly influenced by soil physical and chemical properties. Therefore, soils are expected to differ in terms of their adsorption maxima and bonding energy (Subba Rao *et al.*, 1983). However, little attention has been paid to describe the P adsorption characteristics of arid soils varying widely in their characteristics (Chaudhari and Dhir, 1983). The present study reports the adsorption characteristics of the arid soils of Rajasthan and their suitability for predicting P availability in these soils.

Materials and Methods

Six representative soil samples were collected from near-surface horizon (0-20 cm) of Molasar, Jhanwar, Doli, Jodhpur, Mandor and Gajsinghpura soil series in western Rajasthan. The soils can be divided into two groups. The first four belong to the <1.0% $CaCO_3$ content group, while the last two belong to >1.0% $CaCO_3$ content group. The dominant mineral is illite. Minerals like kaolinites, smectites, chlorites and vermiculites are found in small amounts (Chaudhari and Dhir, 1982).

Physical and chemical properties of the soils were determined by using standard procedures, and are detailed in Table 1.

Table 1. General characteristics of the soils

	Clay (%)	O.C. (%)	NH_4OAC extract. Ca	pH	EC (dS m^{-1})	$CaCO_3$ equiva. (%)	P_2O_5 (kg ha^{-1})	Total Fe (%)	CEC	Texture
Molasar (Typic Torripsament)	7.6	0.34	4.1	8.3	1.33	0.01	16.5	2.20	17.8	Sand
Jhanwar (Typic Haplocambids)	8.1	0.42	5.2	9.2	1.92	0.05	10.1	3.52	20.2	Fine sand
Doli (Typic Haplocambids)	10.4	0.42	7.3	7.6	3.68	0.02	12.1	4.20	19.6	Loamy sand
Jodhpur (Typic Haplocambids)	12.9	0.40	1.9	8.6	0.82	0.04	12.6	4.44	21.7	Sandy loam
Mandor (Typic Haplocambids)	11.6	0.46	6.2	8.3	4.70	2.93	13.1	2.82	28.5	Sandy loam
Gajsinghpura (Typic Cambids)	26.0	0.45	3.9	8.0	1.18	1.41	15.1	5.3	18.2	Loam

For the study lower doses of P were added in group 1 soils (10, 25, 50, 75 and 100 mg P per kg soil) and higher doses of P in group 2 soils (150, 250, 350, 450, and 467 mg P per kg soil), because the latter had higher P fixation power initially.

Soil samples were air-dried, ground and passed through 2 mm sieves for analysis. The adsorption was conducted at room temperature (25°C). Two gram triplicate soil samples were equilibrated for 24 h in 50 ml centrifuge tubes, containing 40 ml of 5 to 160 ppm P in 0.021 $CaCl_2$ solution. Two drops of toluene were added to each tube to minimize the microbial activity. Tubes were shaken twice daily for 5 minutes. After centrifugation and filtration, P in equilibrium solution was determined calorimetrically (Fox and Kamprath, 1970). Sorbed P was estimated by the difference between P added and P remaining in the equilibrium solution. The Langmuir adsorption equation was employed to interpret the reaction of P with soils:

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

where,
C = P concentration of equilibrium soil solution (μg/ml); x/m = P adsorbed (μg/g soil); b is related to the adsorption maxima (μg/g soil) and K to the bonding energy coefficient (μg/ml).

A plot of C/(x/m) vs. C produced a straight line. The slope and intercept of this was used to calculate the adsorption maxima (b) and bonding energy coefficients (K). The phosphorus buffering capacity (PBC) was calculated as the tangent of

Table 2. Regression equations between quantity and intensity of P

Soil	Regression line (y = mx + C)	Correlation
Molasar	y = 11.76x + 126.88	0.999**
Jhanwar	y = 4.341x + 247.99	0.998**
Doli	y = 3.162x + 130.03	0.992**
Jodhpur	y = 8.032x + 96.51	0.994**
Mandor	y = 2.486x - 189.71	0.952**
Gajsinghpura	y = 1.45x + 99.69	0.976**

**Significant at P = 0.01.

the line drawn between P adsorbed (quantity factor) and P in solution (intensity factor).

Results and Discussion

The equilibrium P in the solution (C) was highly correlated (r = 0.952 to 0.999) with P adsorbed by soils (C/(x/m)) in all soils. High correlation for soils suggests that the data followed the Langmuir adsorption isotherm (Table 2). Calculation of Langmuir adsorption parameters (Table 3) revealed that adsorption maxima (b) had a range from 0.023 to 3.74 mg P g^{-1} soil. In general, non-calcareous soils (Molasar, Jhanwar, Doli and Jodhpur) recorded lower values of b than the calcareous ones (Mandor and Gajsinghpura). The bonding energy constant (K) of the soils varied from 0.016 µg ml^{-1} in Mandor to 0.215 µg ml^{-1} in Molasar. K values of soils did not follow any trend with the b values.

Variation in adsorption parameters, viz., b and K values, suggests that soil properties influence P adsorption. The correlation coefficient between adsorption parameters and soil properties suggest that organic matter content and CEC had positive impact on adsorption maxima, whereas none of the soil properties affected the bonding energy constant. Clay content showed no impact on adsorption of P. This was contrary to the observations of Fox and Kamprath (1970). Clays of the arid soils are dominated by 2:1 type minerals (Chaudhari and Dhir, 1982), which do not provide sufficient positive surfaces for adsorption. Similarly, total Fe content of soils may not be effective in P adsorption due to its low content in these soils. Results showed increased adsorption with $CaCO_3$, but the correlation was not significant. However, the organic matter content and CEC of the soils were positively correlated

Table 3. Values of Langmuir parameters in the soils

Soil	Adsorption maxima (b) (mg P g^{-1})	Bonding energy constant (K) (µg ml^{-1})	P buffering capacity (mg g^{-1})
Molasar	0.078	0.215	11.76
Jhanwar	0.0231	0.0174	4.34
Doli	0.316	0.0242	3.16
Jodhpur	0.316	0.0242	8.03
Mandor	3.74	0.016	2.48
Gajsinghpura	0.762	0.061	1.45

Table 4. Per cent phosphate adsorption from different levels of applied P (in non-calcareous soils)

Site	P added (mg kg^{-1} soil)				
	10.67	26.6	53.2	82.7	109.3
Molasar	56.20	36.35	24.79	17.85	14.00
Jhanwar	43.04	40.52	35.77	26.11	35.11
Doli	60.44	52.30	45.32	35.92	37.68
Jodhpur	64.71	47.44	30.60	29.02	19.70

with adsorption maxima. It was possibly due to P bonding to organic matter by replacing the organic hydroxyl group (Harter, 1969) and anion exchange sites present on organic matter. Sanyal *et al.* (1990) also reported the positive correlation between CEC and adsorption maxima.

The phosphorus buffering capacity (PBC) varied from 1.45 ml g^{-1} in Gajsinghpura to 11.76 ml g^{-1} in Molasar (Table 2). Non-calcareous soils had high PBC (3.16 to 11.76 ml g^{-1}) than the calcareous ones (1.45 to 2.48 ml g^{-1}). However, the correlation coefficient between $CaCO_3$ equivalent per cent and PBC were not significant. The PBC was significantly correlated with the adsorption maxima.

High PBC reflects the high labile P content in soil solution. Therefore, the soils of Molasar and Jodhpur, having high PBC, do not require the initial application of P for crop production, but the Gajsinghpura soil needs the initial application of P due to its low PBC content.

The soils varied in per cent P adsorption at different levels of P (Tables 4 and 5). The per cent P adsorption was maximum at lowest application concentration and generally decreased with increased application concentration. The data followed the bonding energy values rather than the adsorption maxima. The maximum per cent adsorption was found in Gajsinghpura soil that also had the minimum bonding energy. This trend could be due to high total Fe, coupled with high $CaCO_3$ content, and fine texture. The finding suggests that P requirement of arid soils with low organic matter and clay content, mainly depend on the $CaCO_3$ content. Ozanne and Shaw (1967) reported that P concentration in equilibrium soil solution should be 0.25 ppm for optimum plant growth. Based on this value the phosphate requirement of non-calcareous soils (Molasar, Jhanwar, Doli and Jodhpur) was worked out to be 42 to 65 kg P_2O_5 ha^{-1}, whereas for calcareous soils (Mandor and Gajsinghpura) it is from 90 to 117 kg P_2O_5 ha^{-1}.

Table 5. Per cent phosphate adsorption from different levels of applied P (in calcareous soils)

Site	P added (mg kg^{-1} soil)				
	163.5	254.1	342.0	437.6	546.0
Mandor	45.3	43.1	44.47	40.44	33.27
Gajsinghpura	63.20	59.30	32.35	30.26	29.10

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