

Index of Phosphate-Binding Energy and Factors Associated with it during Phosphate Adsorption in Himalayan Soils

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Twenty-five Himalayan acid soils of North-West India, were studied for their index of phosphate-binding energy and the soil factors associated with it. The values of index of phosphate-binding energy (k), expressed in the units of $(\text{ml}/\mu\text{g P} \times 10^9)$ varied from 45-362 with an average value of 134. It had a significant and positive correlation with extractable Al and total Fe in a bivariate correlation analysis. However, multiple regression indicated that different forms of Fe (total, amorphous and crystalline), silt and amorphous Al, contributed significantly to the variation in P-binding energy. The relationship between P-binding energy and soil factors suggests the mechanism of P adsorption in terms of two-point-attachment of P-binding in these soils mainly through the colloidal surfaces offered by different forms of Fe oxides.

Key Words: Phosphate-binding energy, Maximum buffering capacity, Langmuir adsorption equation, Soil properties, Acid soils

Introduction

It has been emphasized that the measurement of phosphate buffering capacity is of fundamental importance in considering the phosphate requirement of the soil-plant-system (Holford 1976) because of its indirect relationship with intensity and direct association with quantity factors of phosphate availability. It is also expressed in terms of potential buffering capacity and maximum buffering capacity and both are closely correlated with each other. However, the maximum buffering capacity is considered to be a superior parameter of capacity factor in P availability as it is neither affected by previous additions of P in soils nor the

withdrawal of P by plants (Barrow 1974). It has also been demonstrated that the maximum phosphate buffering capacity is a function, solely of the fundamental absorption properties of soils and is a product of P adsorption maxima (b) and the index of P binding energy (k) when such studies involve the use of Langmuir adsorption equation (Dalal & Hallsworth 1976).

Although the information on the factors affecting P adsorption maxima which represents adsorption sites, exists (Kanabo et al. 1978); there is a wide information gap on the factors influencing P binding energy which reflects the adsorption-desorption

mechanism (Holford et al. 1974).

The objectives of the present study were to report the index of P-binding energy and to find as to which soil factors were associated with it, through simple and multiple regression approach, in some Himalayan soils.

Material and Methods

Twenty-five surface acid soils from 0-15 cm depth, were collected from Himalayan mid hills of North-East India. These soils predominantly fall in the order "Alfisols" and suborder typic hapludalf on the basis of their base saturation and the presence of argillic horizon in their profiles (Verma 1979). They have developed under sub-temperate humid climate and located at an altitude varying between 1000-2000 m above mean sea level with annual temperature ranging from 11 to 35°C and total annual rainfall around 3000 mm. The parent material of the soils is composed of rocks ranging in age from precambrian to paleozoic geological era and they are slates, phyllites, quartzite, schist, granite and gneiss. Among clay minerals identified, illite is the most dominant followed by kaolinite (Sharma 1979). Paddy wheat is the main crop rotation on these soils.

The soil samples were air dried, ground and passed through 2 mm sieve so as to analyse them for various physico-chemical and phosphate adsorption properties. pH of the soils was determined by Beckman pH meter using 1:2 (soil:water) ratio clay content, silt and organic matter were determined by the methods as outlined by Piper (1966). Surface area of the soils was determined by the method of Heilman et al. (1965) using ethylene glycol mono-ethyle ether (EGME). Different forms of Al and Fe were determined according to the procedure outlined by Ballard and Fiskell (1974).

Langmuir adsorption parameters for phosphorus:

The Langmuir adsorption parameters such as P adsorption maxima (b) and the index of P-binding energy (k) were computed from adsorption data, generated by adopting the procedure of Fox and Kamprath (1970) with the exception that equilibration of phosphate with the soil was done for 7 days at $25 \pm 5^\circ\text{C}$, using different concentrations of P ranging from 0-66 $\mu\text{g P/g}$ of soil. P adsorption maxima (b) was calculated from the slope⁻¹ whereas the constant related to P binding energy was measured from the slope/intercept, from a straightline relationship between C and $C/X/m$, using Langmuir adsorption equation: $C/X/m = 1/kb + c/b$ (Olsen & Watanabe 1954) in which C is equilibrium concentration of P ($\mu\text{g/ml}$); X/m is the amount of P adsorbed/unit weight of soil ($\mu\text{g/g}$); b is the adsorption maxima ($\mu\text{g/g}$) and k is a constant related to P binding energy ($\text{ml}/\mu\text{g P}$). Statistical analysis of the data was carried out on the IBM computer at the Indian Agricultural Statistical Research Institute, New Delhi.

Results and Discussion

The overall perusal of the data presented in table 1 suggests that the soils involved in the present study are moderately acidic in reaction (pH 5.1-6.4), with medium to high in organic matter (1.1-2.4%). Fairly good amount of crystalline and amorphous forms of Al and Fe and low content of available P in these soils present a serious problem of P adsorption (Sharma 1979) which is further confirmed by spectacular response of the soils to P application (Mahajan et al. 1975).

Index of P Binding

The index of P binding energy (k) which represents whether the added P is being absorbed loosely or tenaciously on soil surface, ranged between 45 and 362 with an

Table 1 Range and Means of soil properties and different forms of Al and Fe in Himalayan acid soils

Soil properties	(Number of soils=25)	
	Range	Mean
pH	5.1-6.4	5.7
Organic matter (%)	1.1-2.4	1.7
Surface area (m ² /g)	49-90	64.6
Available P (ppm)	5-14	9
Clay%	6-22	15
Silt %	19-51.8	34.7
Sand%	29.6-75.0	50.3
Textural class	Sandy loam to Sandy clay loam	
Forms of Al (ppm)		
i) Exchangeable	2-65	25
ii) Extractable	33-71	52
iii) Amorphous	218-975	437
iv) Crystalline	300-1750	716
v) Total	12250-24500	18144
Forms of Fe (ppm)		
i) Extractable	30-180	83
ii) Amorphous	812-4070	2138
iii) Crystalline	200-6100	1648
iv) Total	12500-30000	22975
*Langmuir parameters		
i) Index of phosphate binding energy (k)	45-362	137
ii) Phosphate adsorption maxima (b)	253-645	433

Phosphate binding energy (k) is expressed in the units of $(\text{ml}/\mu\text{g P}) \times 10^3$ whereas the P adsorption maxima (b) is expressed in $\mu\text{g P/g}$ soil.

average value of 137 when k is expressed as $(\text{ml}/\mu\text{g P}) \times 10^3$. Datta and Sirivastava (1963) also attempted to find the index of P-binding energy of some lateritic and hilly soils of India. They reported these values for lateritic soils in the units of reciprocal of moles/litre ($k \times 10^{-4}$) which when converted to the units of $(\text{ml}/\mu\text{g P}) \times 10^3$, fall in the range of 540 to 4308. These authors further indicated that the values of P-binding energy for

lateritic soils were higher than for hilly soils. The low P-binding energy of hill soils was attributed to the higher organic matter content which reduces the tenacity with which P is adsorbed on the soil surface due to the complexing of sesquioxides by organic anions (Dalton et al. 1952). The P binding energy values reported in the present group of soils approach closely to those reported by above authors for hilly soils, their range was 129 to 442. Ballaux and Peaslee (1975) have shown that P binding energy of soil depends upon the equilibrium P concentration of soil solution and the range of variation in P binding energy reported by them was from 1 to 132 for a mildly acid soil when k was expressed in the units of $(\text{litre}/\text{mg P}) \times 10^3$ for the equilibrium concentration ranging from 40 to 250 $\mu\text{g}/\text{ml}$. The values reported in the present investigation are higher than their values but comparable to those of Olsen and Watanabe (1957). In the earlier studies of Holford et al. (1974) and Holford and Mattingly (1975 b), P-binding energies were computed for two regions of P adsorption which were designated as high and low energy P adsorption surfaces. Consequently, the P binding energy of the former were much greater in magnitude than the latter. The values of index, in the present group of soils, conform to the low energy adsorption surfaces revealing, thereby, that the added P is being held loosely and could be easily available to plants. However, there is a further need to characterize these soils in relation to low and high energy P adsorption surfaces.

Soil factors affecting the index of P-binding energy :

This aspect was examined through simple and multiple regression analysis (table 2, table 3). It was observed that the index of P-binding energy was significantly and positively associated with extractable Al and

Table 2 Simple coefficients of correlation between the Langmuir Index of phosphate binding energy and soil properties

Dependable Vs Independent variables		Coefficients of correlation (r)
The index of phosphate binding energy	pH	-0.118
	Vs	
	OM	0.034
	Clay	0.118
	Silt	0.234
	Surface area	0.194
	Exch. Al	0.289
	Extr. Al	0.433*
	Amorp. Al	-0.158
	Crystall. Al	0.051
	Total Al	0.258
	Extr. Fe	0.231
	Amorph. Fe	0.328
	Cryst. Fe	0.130
Total Fe	0.441*	

*Significant at 5% level

total Fe. There was no direct evidence of the relationship pH, organic matter, clay and silt with P-binding energy as indicated from table 1. However, it has been reported by Ballard and Fiskell (1974) that the influence of these variables in P-retention is indirect because of their association with causal agents of P-retention such as various forms of Al and Fe, which explains why there was no direct relationship between these variables and P-retention. Among the causal agents of P-retention, several investigators have reported that exchangeable Al provides a fairly good index of P-retention in soils (Coleman et al. 1960) but in the present investigation, it did not bear any relationship with P-binding energy which is a component of P-sorption. This may be attributed to the small quantities of exchangeable Al in the

soils whose average pH was above 5 and average exchangeable Al was 25 ppm (table 1).

Likewise, amorphous and exchangeable Al also did not show any significant relationship with P-binding in bivariate regression analysis. However, extractable Al (extractable by ammonium acetate at pH 4.8) exerted a significant influence on it explaining around 18.8 per cent variation ($r = 0.433^*$) and this agrees with the findings of Yaun and Breland (1969) who suggested that the extractable Al provides the single best index of P retention over a range of soils. Since P binding energy is a component of P-retention, such a relationship between extractable Al and P retention is explainable. In this connection, it may be mentioned that hydrous oxides of Al and Fe and edge Al of clay minerals are generally held responsible for P adsorption and that edge Al in silicate clay minerals is considered to behave similar to hydrous oxides of Al in acid soils (Chu & Sherman 1953), it is thus likely that ammonium acetate with pH 4.8, could extract Al of such positions such as edge Al, aquo Al-H₂O and hydrous Al-OH groups of hydrous oxides of Al (Rajan & Fox 1975), which are directly responsible for P retention.

Among different forms of Fe, only total Fe influenced the P binding energy in simple correlation study ($r=0.441^*$) explaining around 19.5 per cent variation in it. This can be ascribed to the availability of sites that could accommodate two point attachment of P-binding on the colloidal surfaces of soils such as Fe oxides (Parfitt et al. 1975, Taylor & Ellis 1978). They further postulated that such a mechanism would produce a stable binding between P and the colloidal surfaces offered by Fe oxides.

An attempt was also made to investigate the combined effect of all the soil properties (OM, clay, silt, surface area, exchangeable, extractable, amorphous, crystalline and total forms of Al and Fe) on the predict-

ability of P-binding energy by multiple regression (table 3). It was observed that the variation in the index of P-binding energy due to the variation in total Fe, amorphous Fe, crystalline Fe, silt, amorphous Al, surface area, organic matter, exchangeable Al, extractable Al, extractable Fe and clay could be explained to the extent of 75 per cent. Among these the partial regression coefficients of total Fe, amorphous Fe, crystalline Fe, silt and amorphous Al were found significant and that the total Fe played the most important role which was evident from the rank order of relative importance (table 3). It is noteworthy to point out that the extractable Al which showed significant association with P-binding energy in simple correlation studies became non-significant during multiple regression analysis and that the various forms of Fe (total, amorphous and crystalline) and amorphous Al, contributed significantly to P-binding energy. It is, however, likely that these soil components form a part of the complex gel as envisaged by Mattson et al. (1950). This gel comprising of Fe_2O_3 along with smaller amounts of organic matter, Al_2O_3 and $Si(OH)_4$ is

considered a major site for P-adsorption and hence P-binding energy in soils.

Table 3 Multiple regression data for the relationship between the index of P-binding energy and soil properties

Dependable variable	//Independent variables	R ²	F-value
Index of P-binding energy (k)	Total Fe**, Amorphous Fe*, Crystalline Fe*, Silt*, amorphous Al*, Surface area, organic matter, exchangeable Al, extractable Al, Crystalline Al, Extractable Fe clay	0.751*	3.01*

// Independent variables arranged in order of their relative importance depending upon the significance level of T values of the partial regression coefficients.

** Partial regression coefficient of independent variables significant at 1 per cent level.

* Partial regression coefficient of independent variables significant at 5 per cent level.

R² It measures the proportion of the total variation about the mean independent variables explained by the regression.

F It tests the significance of R².

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