

## An Investigation on Phosphate Adsorption in Six Sri Lankan Soils in Relation to Their Chemical and Mineralogical Properties

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**ABSTRACT.** *Representative samples of Reddish Brown Earth (RBE), Red Yellow Latosol (RYL), Reddish Brown Latosolic (RBL), Red Yellow Podsollic (RYP), Immature Brown Loam (IBL) and Regosols (REG) were equilibrated with various amounts of  $KH_2PO_4$  in 0.1M KCl for 44 hours with intermittent shaking of 14 hours. After equilibration P concentration of the supernatant solution was determined by molybdate blue-ascorbic acid method. Exchangeable Ca, clay %, organic C, pH and CEC were measured. The mineralogy of these soils was obtained from the literature.*

*Adsorption maximum values of the soils were calculated as P sorption parameters. Relationships between soil characteristics and P sorption parameters were evaluated by regression analysis.*

*Soils are ranked according to their adsorption maxima as follows: IBL < REG < RBE < RYL < RBL < RYP. Values of CEC and the clay % of the soils showed a positive significant correlation with sorption parameters whereas organic C content showed a negative significant correlation. Soil pH and exchangeable Ca did not show a significant relationship with sorption parameters. From the literature it is seen that soils with high amounts of sesquioxides, and comparatively high amounts of kaolinite show high P adsorption.*

### INTRODUCTION

Phosphorus is one of the macro nutrients although its content in plants is less than those of N, K and Ca. As a limiting factor, however, P is more important than Ca and K (Black, 1968). The total content of P in soil is in the range of 0.02 to 0.15 per cent (Mengel and Kirkby, 1982). When phosphatic fertilizers are applied to soils and are dissolved by soil water or when applied as liquid fertilizers, reactions occur among the phosphate, soil constituents, and the non-phosphatic

fertilizer compounds which remove P from the solution phase and render the phosphates less soluble (Sample *et. al.*, 1986).

The principle clay minerals present in tropical soils can be divided into two major groups; those with mainly a constant or a permanent charge and those with mainly a variable charge. The permanent charge minerals are the 2:1, the 2:2 and to a lesser extent the 1:1 layer silicates. The variable charge minerals are the intergrade minerals (mixtures of 2:1 minerals with iron and aluminium hydroxides) both crystalline and amorphous, and allophanes (Zelay and Calhoun, 1971). Predominant soils in the tropics are Oxisols, Ultisols, Alfisols and in certain areas Inceptisols. These soils have both permanent and variable charge minerals such as layer silicates, iron and aluminium hydroxides as well as organic matter (Sanchez, 1976).

During the past few years much research has been done on the adsorption of P to the surfaces of soil particles. Adsorption is defined as the fixation of solutes from a solution on the surface of a solid (Morrill *et. al.*, 1982). It has been shown that a number of soil minerals and amorphous soil colloids are capable of adsorbing phosphates. These include hydrous oxides of Fe and Al (Rajan and Watkinson, 1974; Taylor and Schwertmann, 1974; Parfitt *et. al.*, 1975); silicate clay minerals (Stout, 1939; Dickman and Bray, 1941); Fe and Al organo complexes (Schnitzer, 1969); and Ca carbonate (Kuo and Lotse, 1972). Phosphorus in the soil solution may also get precipitated to form sparingly soluble compounds like Ca, Fe and Al phosphates (Saeki and Okamoto, 1957; Udo and Ogunwale, 1977; Mengal and Kirkby, 1982). Many researchers have found that organic matter affects the reactions of P in soils.

Equilibrium methods have been widely used to characterize P adsorption in soils. Several different adsorption equations or modifications of these have been used. Langmuir is one of the commonly used equations. It was first applied to P adsorption in soil by Olsen and Watanabe (1957). This equation is usually expressed as

$$X = \frac{KCM}{1 + KC}$$

where X stands for the weight of P adsorbed per unit weight of soil, C is the equilibrium P concentration, M is the adsorption maximum and

K is the equilibrium constant. This equation can be rearranged as,

$$C/X = 1/KM + C/M$$

Therefore, if the Langmuir equation applies, a plot of C/X vs. C will be a straight line and K and M could be calculated using the slope and the intercept of the plot.

This investigation was undertaken to study the phosphate adsorption in six soils from Sri Lanka as related to their clay mineralogy, physical and chemical properties.

### MATERIALS AND METHODS

Soil samples representing Reddish Brown Earth (Rhodustalfs), Red Yellow Latosol (Eustrustox), Reddish Brown Latosolic (Rhodudults), Red Yellow Podsolc (Tropudults), Immature Brown Loam (Ustropepts) and Regosol (Quartzpsamments) were collected from various parts of Sri Lanka at a depth of 0–15 cm. The samples were air dried and passed through a 2 mm mesh sieve. Soil samples were analyzed for clay %, pH, organic C content, CEC and exchangeable Ca.

#### Analyses of soil

- Clay % : Determined by the pipette method.
- Soil pH : Measured in 1M KCl using a 1 : 2.5, soil : solution ratio.
- Organic C : Determined by the Walkley – Black wet combustion method.
- CEC : To determine CEC, soil samples were saturated with Na using 1M NaOAC and the adsorbed Na was extracted by treating the samples with NH<sub>4</sub>OAC. Sodium concentration of the leachate was measured using an atomic absorption spectrophotometer (Chapman, 1965).

Exchangeable Ca : Determined by extracting with 1M  $\text{NH}_4\text{OAC}$  and measured using an atomic absorption spectrophotometer.

### P Adsorption experiment

Five g of soil was weighed in 250 ml conical flask. To each soil 50 ml of 0.1M KCl was added containing increasing concentrations of P in form of  $\text{KH}_2\text{PO}_4$ . The P levels were 0, 20, 40, 60, 80 and 100 mg of P per litre. These samples were equilibrated for 44 hours with intermittent shaking of 14 hours. All treatments were replicated three times. The P in the supernatant solution was determined by the method of Murphy and Riley (1962). The amount of P adsorbed was calculated by the difference between the initial and the final P concentrations. The data obtained from this sorption experiment were fitted to the linear form of the Langmuir equation.

### Literature survey

A literature survey was carried out to identify the mineralogy of these six Sri Lankan soils.

## RESULTS AND DISCUSSIONS

### Soil properties

Physical and chemical properties measured for the samples are given in Table 1.

### P Adsorption parameters

Graphical representation of  $C/X$  vs.  $C$  for soil samples are presented in Figure 1. The linear regression lines of RBE, RBL, RYL and REG were significant at 0.001 probability level, whereas IBL and RYP were significant at 0.05 and 0.01 probability levels respectively. These regression lines indicate the conformity of the experimental P adsorption data to the linear Langmuir isotherm. Estimates of P

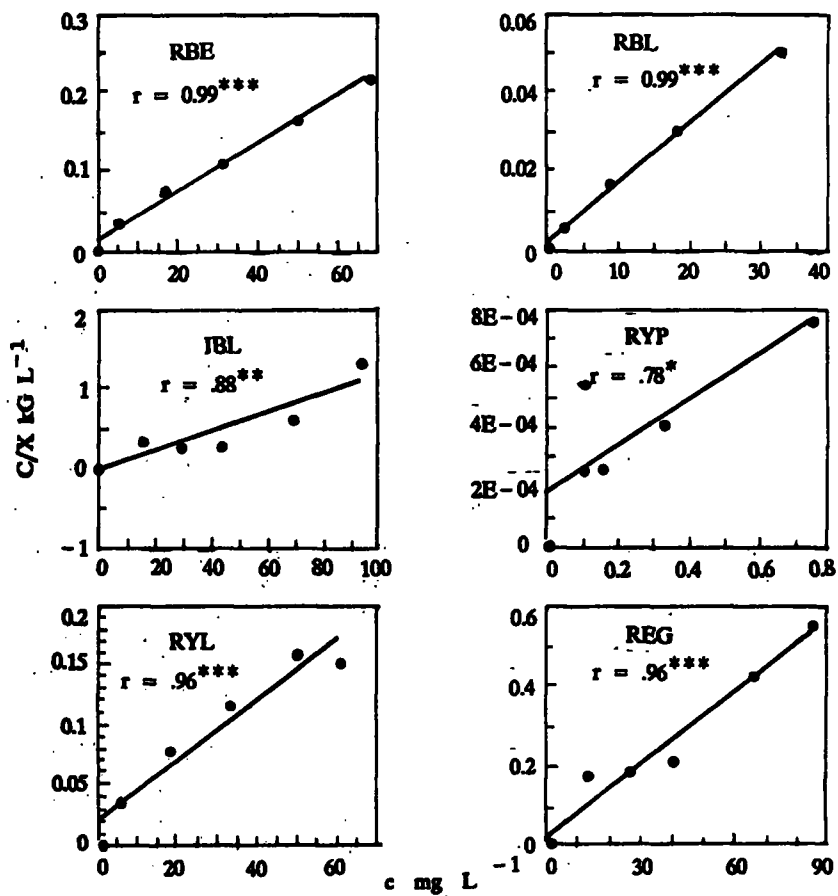


Figure 1. Graphical representation of the linear Langmuir isotherms.

\*, \*\* and \*\*\*, statistically significant at 0.05, 0.01 and 0.001 probability levels, respectively.

adsorption maxima along with the corresponding equilibrium P concentration are useful parameters in comparing P sorption behaviour of various soils (Yuan and Lucas, 1982) and in studying soil P levels for optimal plant growth (Woodruff and Kamprath, 1965).

Adsorption maxima were calculated using the slope of the regression equation of the Langmuir isotherm. The adsorption maximum values were 81.31, 176.2, 351.18, 449.77, 692.73 and 1624.93 mg of added P per Kg soil for IBL, REG, RBE, RYL, RBL, RYP respectively. Thus soils can be ranked using the adsorption maxima values as follows: - IBL < REG < RBE < RYL < RBL < RYP.

Table 1. Some physical and chemical properties of the six soils used in this study.

SOIL	ABBR- -EVATION	CLAY %	O.C. %	pH	CEC cmol/Kg	EX. Ca cmol/Kg
+ Reddish Brown Earth * Rhodustalfs	RBE	18.9	0.61	5.4	10.8	76.0
+ Reddish Brown Latosolic * Rhodudults	RBL	42.1	0.46	5.0	20.6	98.8
+ Immature Brown Loam * Ustropepts	IBL	9.2	0.65	5.3	10.5	93.8
+ Red Yellow Podsollic * Tropudults	RYP	66.9	0.19	6.2	34.3	80.8
+ Red Yellow Latosol * Eustrustox	RYL	22.1	0.65	5.9	11.5	103.1
+ Regosol * Quatzpsamments	REG	15.2	0.50	6.4	9.15	98.1

+ Great Soil Group name

\* 7th Approximation name

### Statistical analysis for P adsorption data

Simple regression technique was used to study the relationships between soil characteristics and P adsorption parameters. The parameters used were clay %, organic C %, pH, CEC and exchangeable Ca in the samples.

Clay content showed a positive significant relationship with P adsorption ( $r = 0.985^{**}$ ). Similar results have been reported by Sree Ramulu *et. al.*, (1967) and Fox and Kamprath (1970). It is to be expected that soils with a high clay content would adsorb more phosphate, since clay minerals are largely responsible for P adsorption in most mineral soils.

Mineralogical composition of RBL, RBE, RYP and IBL is presented in Table 2 (Mapa, 1991). According to Kalpage *et. al.*, (1963) RYL consist of 90% of kandite, 5% hematite and trace amounts of illite. The mineralogy of REG was not available. Comparison of clay mineralogy with P sorption data indicates, that generally soils with higher contents of sesquioxides and relatively larger amounts of kaolinite, adsorb high amounts of phosphate.

Organic C content of samples showed a negative significant relationship with P adsorption ( $r = -0.908^*$ ). This result is in agreement with the findings of Nagarajah *et. al.*, (1970). High amounts of organic C reduced the P adsorption by colloids possibly due to the competition between organic acids and phosphate for adsorption sites.

Soil pH and exchangeable Ca did not show a significant relationship with sorption parameters possibly because the soils did not show much variation in pH values and exchangeable Ca contents. These findings are contradictory with the results of other researchers. (Wild, 1950; Saeki and Okamoto, 1957; Moreno *et. al.*, 1960; Udo and Ogunwale, 1977; Mengel and Kirkby, 1982; Lavedier and Karam, 1984 and Sample *et. al.*, 1986).

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\* and \*\* refers to statistical significance at 0.01 and 0.001 probability levels, respectively.

Table 2. Mineralogical composition of the clay fraction of four soil samples used in this study. Abundance on a scale of 0–10.

Clay Mineral	Soil			
	RYP	RBE	RBL	IBL
Kaolinite	6.0	8.0	8.0	4.0
Smectite	–	1.0	1.5	3.0
Vermiculite	–	0.5	0.5	1.0
Mica	0.5	0.5	–	2.0
Hydroxy Interlayered Vermiculite	1.0	–	–	–
Gibbsite	2.0	–	–	–
Boehmite	0.5	–	–	–

Source: Mapa (1991).

CEC values showed a significantly positive relationship with P sorption ( $r = 0.976^{**}$ ). One reason for this could be the fact that CEC was measured at pH of 8.2, where as the P adsorption experiment was carried out at a pH range of 5.0–6.4 depending on the soil. It is known that tropical soil contain minerals with variable charges. These minerals may exhibit a net negative charge at higher pH, thus contributing to CEC, and at low pH they may exhibit a net positive charge thus contributing to the anion adsorption.

\* and \*\* refers to statistical significance at 0.01 and 0.001 probability levels, respectively.



In addition to adsorption, precipitation may take place during the experiment, which may remove phosphate from solution phase. Since  $\text{KH}_2\text{PO}_4$  was used as the P source, K was added simultaneously with phosphate. It is likely that these K may replace cations from the exchangeable sites and these replaced cations may form precipitates with phosphate. Higher the CEC higher would be the amount of cation replaced and the precipitation of phosphate with cations. Similar results were observed by Akinremi and Cho (1990).

### CONCLUSIONS

1. According to the calculated adsorption maxima values soils can be ranked as follows:  
 $\text{IBL} < \text{REG} < \text{RBE} < \text{RYL} < \text{RBL} < \text{RYP}$ .
2. A significant positive relationship was observed between P adsorption and clay % which indicates that clay fraction is largely responsible for P adsorption in these soils.
3. P adsorption showed a significant negative relationship with organic C content, possibly due to the competition between organic acids and phosphate for anion adsorption sites.
4. The soils used in this study did not show much variation in their pH values and exchangeable Ca contents. Thus, a significant relationship was not observed between either of these parameters and P adsorption.
5. The CEC values of soils showed a significant relationship with P adsorption. One reason for this could be due to the variable charges of the colloids. These colloid exhibit a net negative charge at higher pH, thus contributing to CEC, and a net positive charge at low pH thus contributing to the anion adsorption. Another reason may be due to precipitation of P by cations like Ca, Al, Fe released to the solution phase by K ions of the  $\text{KH}_2\text{PO}_4$ .

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