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RESEARCH ARTICLE

PHOSPHATE SORPTION CAPACITY OF SOME TROPICAL SOILS ON BASEMENT COMPLEX OF SOUTH WESTERN NIGERIA

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ABSTRACT

Phosphate sorption isotherm is a valuable tool for the management of P fertility in soils. This study was conducted to examine how P sorption characteristics were influenced and could be predicted from selected properties of tropical soils. Langmuir and Freundlich equation were adopted in the evaluation and estimation of P sorption parameters in nine soils types of South Western Nigeria developed on basement complex. Two profile pits were dug per soil type where they were dominant (predetermined by Smyth and Montgomery, 1962). The morphological attributes of the soil profile were described and soil samples were taken from pedological horizons for laboratory analysis. Same soil types were bulked and P sorption were determined using 11 concentrations of P and three replicates.. The P sorption data for these soils were slightly better fitted to Freundlich equation than the Langmuir equation. Oxalate extractable Al (Al_{ox}) and Clay particles were the properties that were best correlated with sorbed P. This suggest that oxalate Al oxide with silicate clay play a significant role in P sorption.

INTRODUCTION

Decline in soil fertility, low crop yield and problems of environmental degradation are characteristic of tropical agriculture. In many cases, the decomposition of soil organic matter and plant residues is the main source of plant nutrients in low-input small-scale farming systems of the tropics (Gijsman *et al*., 2002). However, limited availability of P is a major constraint to plant growth in highly weathered soils of the tropics. Thus, a better understanding of soil P dynamics is required to improve management practices in tropical agroecosystems most especially factors affecting availability of soil and fertilizer P.When P is added to the soil, especially Alfisols, Oxisols and Ultisols, some of it is converted into forms that are not readily available to plants. This immobilization is often referred to as fixation or adsorption whereby P is held onto the surfaces of soil clay, $CaCO_3$, Fe and Al-oxides and hydroxides or organic complexes. These soil components act singly or in combination to influence sorbability or desorbability of soil P (Burt *et al*., 2002; Giesle *et al*., 2005). Although the total quantity of P and plant-available P often differ greatly in different tropical soils, adsorption isotherms has been used to characterize and compare P sorption in soils. This process involves equilibrating the soil with several known concentrations of P over a 24-hours period (Ige *et al*., 2005). The decrease in solution concentration is used to determine sorbed P and the data generated from the adsorption isotherm is fitted into two empirical models of Freundlich and the Langmuir adsorption equations to calculate sorption parameters such as sorption maxima and affinity. Agbenin, (2003) reported that ferruginous Fe nodules were the major P sinks in several soils from semiarid regions to arid regions. He observed that the concentrations of oxalate- and dithionite-extractable Fe and Al in 30 of the soils used to generate the P sorption index was two to three times greater in the subsurface than in surface soils. A large area of the rain forest and savannah zone of southern Nigeria is developed on basement complex mostly Gneiss (Smith and Montgomery 1962). For Nigerian savannah soils, dominated by Alfisols or Tropical Ferruginuous soils, crystalline Fe is the predominant Fe form (Juo *et al*., 1974; Jones and Wild, 1975). They cover about 60–70% of tropical areas, where they are mainly represented by Alfisols, Oxisols and Ultisols according to the US Soil Taxonomy (Soil Survey Staff, 2003) in the forest zone. The Ibadan series, Egbeda, Apomu, Gambari and Origo series etc. according to Smith and Montgomery (1962) cover over 55% of the soils of this region. Although, soils of southwestern Nigeria have been greatly studied, detailed studies concerning the fate of added P has not been extensively investigated. Therefore this work set out to determine the P sorption capacities of representative soils of south western Nigeria in relation to soil properties and depth, and use the information to develop P management strategies where such soils are found.

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MATERIALS AND METHODS

Study site

The research was carried out on nine soil series in the south western part of Nigeria according to Smyth and Montgomery (1962) local soil classification, these soils are rich in sesquioxides of iron and aluminium. The soils are: Ibadan series (ferric luvisol), Egbeda series (plinthic luvisol), Apomu series (gleyic luvisol), Gambari series (eutric planosol), Origo series (vertic luvisol), Iwo series (ferric luvisol), Itagunmodi series (chromic luvisol), Ondo series (not classified) and Jago series (eutric gleyisol). The experiment was conducted in two replicates across the region and a profile pit was dug at each location making a total of 18 profile pits. Samples were taken from all the recognised horizons but for the purpose of this work the first three identified horizons (Ap, AB, Bt not conventional designation yet) were used for sorption test representing the ploughed horizon and two subsoil horizons. Samples were air dried and ground to pass through 2mm sieve. Extractable phosphorus was determined in Mehlich-3 extractant by equilibrating 2.5 g of air dried soil sample with 25 ml of Mehlich-3 extracting solution for 5min and filtering through Whatman No. 40 filter paper (Mehlich, 1984). Ammonium oxalate extractable P, Ca, Mg, Fe, Al and Mn were measured by shaking 0.5 g of soil with 20 ml of ammonium oxalate extracting solution for 4 h in the dark and then filtered using Whatman No. 40 filter paper (Jackson *et al*., 1986). The different soil extracts were analyzed colorimetrically for P using the molybdate blue method (Murphy and Riley 1962). Ammonium oxalate P, Mg, Fe, Al and Mn were determined by ICP technique. The exchangeable cations and the cation exchange capacity (CEC) of the soil were determined using the ammonium acetate method (McKeague 1978). The soil was saturated with ammonium acetate and the leachate was analyzed for exchangeable cations. To determine the cation exchange capacity of the soil, the saturated soil was washed with ethanol to remove free ammonium ions and then with NaCl solution to remove adsorbed ammonium ions, which were measured using the auto- analyzer. Particle size distribution was determined using hydrometer method (Boyoucos, 1962), pH in ratio 1:2 Soil:H_2O.

Phosphorus sorption index

Multiple points isotherm was generated using 10 concentrations of P in 0.01 M KCl. P concentrations used were: 0, 1, 2, 5, 10, 25, 50, 75, 100, 125 $mgkg^{-1}$. Measurement at each concentration was carried out in triplicate making a total of 81 samples at each concentration. The procedure involved equilibrating 2g of air dried soil with 20 ml of P solution as KH_2PO_4 prepared in 0.01 M KCl of the respective P concentrations and shaken on an end–to-end electric shaker in a 50-ml centrifuge tube for 24-hours. The supernatant was separated by centrifuging at 7000 x g for 10min followed by filtering through a 0.45µm filter using suction pump. The P concentration was determined colorimetrically by the molybdate blue method. The amount of P sorbed was determined by the difference between the amount of P added to the soil and the amount of P in the solution at equilibrium. The data obtained were fitted to Langmuir and Freundlich adsorption models.

Linearized form of Langmuir model is given by:

$$C/S = 1/bS_{max} + C/S_{max} \qquad [1]$$

Freundlich model is given by:

$$S = K_f C^n \qquad [2]$$

Linearized log $$\mathrm{Log}S = \mathrm{Log}K_f + n\,\mathrm{Log}C \qquad [3]$$

where C is the equilibrium concentration (mg/kg), S is P adsorbed (mg/kg soil), b is a constant related to the binding energy, S_{max} is adsorption maxima (mg/kg soil), K_f is the Freundlich adsorption coefficient.

A plot of C/S against the equilibrium P concentration (C) gives a slope whose reciprocal is the adsorption maxima.

RESULTS AND DISCUSSIONS

Soil characteristics

The nine soils were representative of the major soils of south western Nigeria and covered a wide range of soil properties and the distribution of soil groups (Table 1). The soils were mostly slightly acidic to acidic with a pH range of 4.66 to 6.47 and an average pH of 5.48. This is expected since most of the soils are highly weathered and leaching have decreased the surface pH in some of the soils. Clay content is highly variable in some of the soils (4.0 to 43%), oxalate Al_{ox} and Fe_{ox} ranged between 130 and 1079 (mg/kg) and 274 and 1639(mg/kg), respectively. The Mehlich-3 extractable P was very low and not enough for optimum crop production in most of the soils excepts in Iwo series where Mehlich-3 P was very high (maximum in the top soil was 47 mg/kg). This could be due to long time continuous application and accumulation of fertilizer P to this soil. For some of the soils with high Mehlich-3 P the initial P sorbed was low but increased with increasing solution P concentrations, this is in agreement with the findings of Martha *et al*., 2009 and Robarge, 1999, on soils of Ethiopia in East Africa.

Table 1: General properties of nine soils series south western Nigerian soils

Soil properties	Mean	Median	Minimum	Maximum
CEC (Cmol/kg)	7.83	7.81	2.28	13.12
pH (H20)	5.48	5.40	4.66	6.47
%Sand	68.37	68.00	44.00	86.00
%Silt	12.77	12.67	6.00	22.40
%Clay	18.86	14.00	4.00	43.00
[1]Av.P(mg/kg) (M3)	6.46	2.95	0.29	47.81
TP(mg/kg)	268.92	222.50	112.50	750.42
Al_{ox} (mg/kg)	623.08	576.40	130.00	1079.20
Fe_{ox} (mg/kg)	978.66	967.20	274.00	1639.47
Mg_{ox} (mg/kg)	149.85	140.80	40.40	529.33
Mn_{ox} (mg/kg)	302.35	276.13	8.00	917.40
P_{ox} (mg/kg)	73.02	22.67	8.20	729.48

[1] Av.P is available P measured using Mehlich-3extractant.
TP is total soil P

Phosphorus Sorption

For sorption isotherm all the soil samples were typical of soil P sorption behavior down the profile with Langmuir linear model except in three of the soil series. However, the sorption data was better fitted to Freundlich model than the Langmuir model as judged by the coefficient of determination (R^2). Table 2a and 2b shows the values of S_{max} and K_f across the soil series and down the profile. The S_{max} was greatest in Ondo series followed by Gambari and then Itagunmodi with the values of 885 mg/kg, 674 mg/kg and 624 mg/kg, respectively. These values were within the range obtained for Uganda urban soils receiving urban and animal wastes (Kulabako *et al*,. 2007). Iwo, Origo and Jago series has the smallest S_{max} values of 92 mg/kg, 101 mg/kg and 140 mg/kg, respectively. These however, conformed to the range of S_{max} obtained by Agbenin (2003) for some savanna soils of Nigeria. Figure 1 shows the variability observed in the nine soil series down the profile. Ondo, Apomu and Origo showed an increasing S_{max} down the soil profile, it decreases down the profile in Ibadan and Jago series, while Iwo, Egbeda, Gambari and Itagunmodi showed no consistent pattern of P sorption with soil depth.

Table 2a: Langmuir sorption maxima in the soil profile (mg/kg)

Soil series	Ap horizon	AB horizon	Bt horizon
Egbeda	208.28	355.91	217.86
Itagunmodi	352.44	623.96	412.19
Iwo	91.85	361.31	209.55
Ibadan	321.38	291.40	243.61
Gambari	309.97	253.80	674.19
Ondo	610.55	752.76	885.29
Apomu	159.13	220.09	232.72
Jago	300.45	222.19	100.80
Origbo	140.12	217.77	307.40

Table 2b: Freundlich adsorption coefficient in the soil profile(L/kg)

soil series	Ap	AB	Bt
Egbeda	47.9	71.4	89.3
Itagunmodi	61.2	108.2	100.3
Iwo	3.7	14.7	40.0
Ibadan	40.9	56.4	78.2
Gambari	50.0	104.3	111.4
Ondo	111.7	142.0	153.4
Apomu	27.2	28.4	75.6
Jago	35.3	6.2	24.3
Origbo	23.7	46.3	55.6

The values for K_f (Freundlich adsorption coefficient) are given in table 2b. Of the nine soils, K_f was greatest in Ondo series and it increased down the profile followed by Itagunmodi and Gambari series which also showed increasing sorption coefficient with depth (Table 2b). The smallest value of the Freundlich sorption coefficient was obtained in Iwo series (3.7 $mgkg^{-1}$) but this value increased with depth reaching 40 $mgkg^{-1}$ at the Bt horizon. Unlike S_{max}, K_f showed a more consistent pattern of P sorption with depth as shown in Figure 2. The Freundlich sorption parameter (K_f) increased down the profile in all the soil series except in Jago series where it appeared to decrease with depth similar to the pattern of S_{max} with depth.

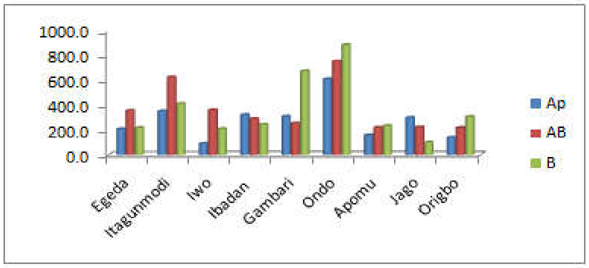

Fig. 1: Variation in Langmuir sorption maxima in the soil profiles (mg/kg)

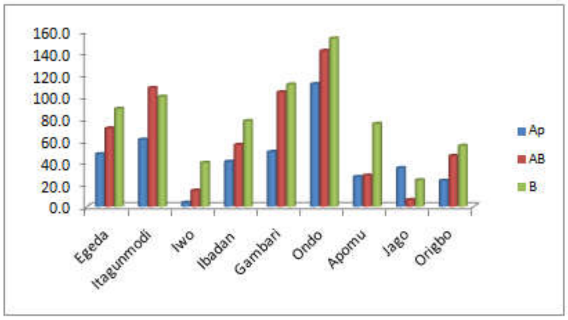

Fig. 2: Variation in Freundlich adsorption coefficient in the soils(L/kg)

Relationship of Phosphorus Sorption Maximum to Soil Properties

Phosphorus sorption maximum for the soils correlated positively with Al_{ox} (r = 0.63) and clay (r = 0.69), and was highly negatively correlated with sand (r= -0.71) (Table 3). The positive correlation with Al_{ox} and weak negative correlation with pH may suggest that the primary P sorption sites in these soils are not carbonate clays. Thus, of all the principal component of the soil measured Al_{ox}, P_{ox}, Fe_{ox}, Mg_{ox} and Mn_{ox}, it was only Al_{ox} that was significant ($p< 0.001$) explaining about 80% of the variations in S_{max}. Although Fe_{ox} is an important P sorbent, it was not highly correlated to Smax, this was also observed by Agbenin and Tiessen (1994) on semi-arid soils of Brazil. As similar result was obtained by Martha *et al*., (2009) on soils from eastern Africa. Concentrations of Al_{ox} in the nine soils ranged between 130 mg/kg and 1079 mg/ kg (Table 1), well with the range found in savanna Alfisols of Nigeria by Agbenin (2003).

Conclusion

Nine soils from south western part of Nigeria were studied and the results obtained show a high correlation between clay content, Al_{ox} and P sorption. Some of the soils have a high tendency to adsorb applied P than others, which calls for different P management approaches for these soils Both Langmuir and Freundlich model confirmed that Ondo soil series has the greatest capacity to fix applied P. Therefore, the differences in sorption parameters amongst soils and their variation within depth must be taken into consideration when deciding the fertilizer rate for P in these soils.

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