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Phosphorus sorption characteristics of some selected soil of the Nigerian Guinea Savanna

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ABSTRACT
This study evaluated soil samples from the Nigerian guinea savanna areas of Minna, Mokwa and Ankpa for their Phosphorus (P) sorption characteristics. The samples were equilibrated in 30 ml of 0.01M $CaCl_2$ containing various amounts of P as KH_2PO_4 to give 0, 25, 50, 100, 200, 400, 800 and 1000µg L^{-1} P for six days at room temperature. Some soil properties as well as P sorption characteristics were studied in the samples. The adsorption isotherm of the samples showed different curves for samples of each soil series. It was evident from the curves that rates of P adsorption increased with increased concentrations of P, but at a certain level of higher concentration, the level of P became almost constant and had no more capacity to adsorb P. P adsorption capacity decreased in the following order Ankpa > Mokwa > Minna. The relative capacity of each soil sample to adsorb P was significantly and positively correlated with the soil's clay content (r =0.81*), exchangeable acidity (r= 0.96**) and pH (r = 0.98**) but negatively correlated with the soil's organic carbon content (r = -0.96**). The study showed that Ankpa soil required more P fertilization than the other soil samples for plant growth. Management practices involving the use of organic materials and liming as a basis for P sorption reduction will be useful for crop production in Nigeria especially in the southern guinea savanna agro ecological region.

Keywords: Adsorption isotherm, Ecological region, Equilibration, Fertilization, Sorption characterization.

INTRODUCTION
In tropical and subtropical acidic soil low Phosphorus (P) availability is a factor that limits plant growth. When soil phosphate levels are too low, Phosphorus deficiency in plants represents a major constraint to world agricultural production (Palomo et al. 2006). The fate and efficiency of native and applied phosphorus therefore remains one of the biggest problems in arable crop production in the tropics. One problem is
that fertilizer P can largely be fixed by oxides, hydroxides and oxyhydroxides of Fe and Al and clay minerals in acidic soil, which makes it less available or effectively unavailable to plants (Shen et al. 2001). This is because the availability of both applied and native phosphorus is largely controlled by sorption and desorption characteristics of the soil.

Variable charge minerals are also major components of most soil in the tropics that make phosphorus unavailable to plants. Such is the case with Nigerian soil. It is dominated by sesquioxides and low activity clay content (Bala, 1992). The most likely areas appear to be those dominated oxisols, ultisols and alfisols. The low amount of total and available P in these soil variations makes it imperative that problems associated with phosphorus availability are investigated. Already, the widespread occurrence of P deficiency in most arable land in Nigeria has led to intensive use of P fertilizer. Osemwotai,et al. (2005) observed that in some soil of the savanna zones of Western Africa, P deficiency is so acute that some P fertilizer must be applied to achieve even a moderate yield.

While some detailed studies have been carried out on soil from the savannas of Nigeria, very little attention has been given to the soil of the Southern Guinea part of the Nigerian Savanna especially in terms of phosphorus sorption and desorption characteristics., Therefore, a proper understanding of the mechanism of P retention in Nigeria is very important to establish good management practice for P fertilizer. The objective of this study was to evaluate the P sorption characteristics of some selected soil samples of the Nigerian Guinea Savanna with a view to efficient management of P fertilizer.

MATERIAL AND METHODS

Soil sampling and characterization

Soil samples were collected from three different locations of different pedogenic characteristics. These locations were (i) Minna ($9^0$40'N, $6^0$30'E) (ii) Mokwa ($9^0$18' N $5^0$05'E) and (iii) Ankpa ($6^0$32'N, $7^0$15'E) in the Guinea Savanna region of Nigeria. These soil types were classified as alfisol, ultisol and oxisol respectively according to USDA Soil Survey Staff (1976).

Soil samples were collected from a depth of 0 – 20cm, they were air dried, sieved and then passed through 2mm sieve. Particle size distribution was determined by the hydrometer method after dispersion with sodium hexametaphosphate according to the procedure described by I.I.T.A. (1976). pH values of the samples were determined in distilled water and 1.0N KCl solution using a soil - solution ratio of 1:2 (McLean, 1982). Organic carbon was determined by the Walkley – Black wet oxidation method (Allison, 1965). Exchangeable basic cations were extracted with neutral normal ammonium acetate with potassium (K) and sodium (Na) determined by flame photometry and calcium (Ca) and magnesium (Mg) by EDTA titrations. Exchange acidity was determined by shaking the samples with 1.0 M KCl and titrating them with 0.1 M NaOH. Available P was determined by the Bray P 1 method (Bray and Kurtz, 1945). Selected properties of the soil samples are given in Table 1.

Phosphorus sorption studies

Two grams of 2 mm sieved soil was placed into 50ml centrifuge tubes. Soil samples were equilibrated in 30 ml of 0.01M $CaCl_2$ containing various amounts of P as KH_2PO_4 to give 0, 25, 50, 100, 200, 400, 800 and 1000µg L^{-1} P for six days at a room temperature. Two – three drops of tolune were added to minimize microbial activity. Suspensions were shaken twice daily for 30 minutes and at the end of the sixth day, they were centrifuged at 10,000rpm and filtered through whatman No. 42 Filter paper. Phosphorus content in the supernatant solution was determined colorimetrically according to the procedure described by Murphy and Riley (1962). Phosphorus that disappeared from a solution was considered as sorbed and the sorbed phosphorus was plotted against phosphorus concentration in the solution to obtain a P sorption isotherm.

The P sorption data for the soil samples used in this study were fitted into the following form of Langmuir equation: $C/X = 1/kb+c/b$. Where C = P concentration in equilibrium solution, X = P adsorbed by the soil (mg P kg^{-1}), b = adsorption maximum (mg P kg^{-1}) k = a constant related to the bonding energy of the soil for P or affinity constant.

Table 1. Physico – chemical properties of the three soil series.

Soil properties	Series A	Series B	Series C
Sand ($g\ kg^{-1}$)	640	620	763
Silt ($g\ kg^{-1}$)	100	140	36
Clay ($g\ kg^{-1}$)	260	240	161
Textural class	Sandy Clay Loam	Sandy Clay Loam	Sandy Loam
pH ($CaCl_2$)	5.4	5.2	4.6
Org. C. ($g\ kg^{-1}$)	8.9	6.8	5.3
Exch.Ca ($cmol\ kg^{-1}$)	2.20	1.84	1.40
Exch.Mg ($cmol\ kg^{-1}$)	0.63	0.89	0.71
Exch.K ($cmol\ kg^{-1}$)	0.26	0.36	0.40
Exch.Na ($cmol\ kg^{-1}$)	0.14	0.16	0.17
Exch.acidity ($mmol\ kg^{-1}$)	0.02	0.02	0.04
Available P. ($mg\ kg^{-1}$)	4.21	3.30	2.78

Key: Series A = Minna soils, Series B = Mokwa soils and Series C = Ankpa Soils

RESULTS AND DISCUSSION

Physico – chemical properties of the studied soil.

Selected physico - chemical properties of the soil samples that were studied are shown in Table 1. The samples were acidic with pH values ranging from 4.6 - 5.4. The particle size distribution showed that the texture of the soil varied from sandy loam (Ankpa) to sandy clay loam (Minna and Mokwa). Although the organic carbon content of the soil was generally low, Minna soil had the highest value of 8.9g kg^{-1}. Jones and Wild (1975) reported that low to medium organic carbon rate for savanna soil was attributed to paucity of vegetation cover, rapid mineralization of organic matter, inadequate return of crop residue, bush burning and short fallow periods. Exchangeable bases were in the order of Ca>Mg>K>Na for all the locations.

Phosphate adsorption isotherms

Phosphate adsorption isotherms of the three soil series used in the study were determined by plotting the equilibrium concentration of phosphate (C) against the amount of phosphate adsorbed (X). The adsorption isotherm of the three soil series showed that all the soil series exhibited different curves. Comparing the highest amount of P adsorbed in the three soil series, it was evident that each soil series had a different capacity to adsorb P (Table 2). The result of the study showed that Ankpa soil series had the highest value of maximum adsorption of 180.27 mg kg^{-1} followed by Mokwa and Minna series with maximum P adsorption of 138.50 and 105.21mg kg^{-1} respectively. The highest value of adsorption in the Ankpa series may be due to organic matter content and clay lattice. Similar adsorption isotherms have already been reported by and Sarfaraz et al. (2009) Agbenin, (2003) Li et al. (2000),These authors reported that the main soil components influencing phosphate sorption include: soil pH, nature of clay content, organic matter and amorphous Fe and Al oxides.

A graphical representation of the adsorption isotherms of the three soil series with different curves is illustrated in Figure 1. The curve followed a smooth plateau pattern. It is evident from the curves that the rate of P adsorption increased with an increase of P concentration, but at a certain point of higher concentration, the level of P became almost constant having no more adsorption capacity. The relative amount of P adsorbed was dramatically higher at a low concentration than at a higher concentration.

This suggests that the reaction between phosphate and the soil was rapid on initial contact. This perhaps could have been due to a low available P content (Table 1) resulting in high adsorption potential at the surface. Similar observations have been reported elsewhere by Bala, (1992).

Langmuir adsorption isotherm showed a good fit when sorption data were fitted to the adsorption equation by taken C/X against C (Figure 2). The highest R^2 value of 0.985 was observed for the Mokwa series followed by the Ankpa series with a value of 0.976 and the lowest was observed in the Minna series with a value of 0.962 (Figure 2).

The comparison of the Langmuir adsorption maxima (b) for the three soils series showed that maximum values of adsorption were 192.82, 144.53 and 113.96mg kg^{-1} for Ankpa, Mokwa and Minna soil samples respectively (Table 4). It was also observed that the Langmuir evaluation gave higher maximum value for adsorption than the actual calculated value (Table 2). The affinity constant (K) was in a decreasing order of Ankpa> Minna >Mokwa. Variation in the adsorption maxima (b) and affinity constant (k) could be related to the soil sample's parent material content and mineralogy, this was also observed by Uzoho and Oti, (2005).

Correlation between some soil properties with Langmuir constants (Table 4) showed that P adsorption was significantly correlated with clay (r = 0.81*), exchangeable acidity (r = 0.96**), and pH (r = 0.98**) but negatively correlated with organic C (r = - 0.96**). Similar findings were reported by Juo and Fox, (1977), Ayodele and Agboola, (1981) and Agbenin,(2003).

Table 2. The maximum adsorbed P by three soil series.

Soil series	Maximum P adsorbed (mg kg^{-1})
Minna series	105.21
Mokwa series	138.50
Ankpa series	180.27

Table 3. Comparison of Languir adsorption maxima (b) and affinity constant (k) for three soil series.

Soil series	Adsorption maxima (b) (mg kg^{-1})	Affinity constant (k) (ml μg^{-1})
Minna series	113.96	2.83
Mokwa series	144.53	2.42
Ankpa series	192.82	3.60

Table 4. Correlation between some soil properties and adsorption maxima

Soil properties	Adsorption maxima (b)
Soil pH	0.98**
Exch. Acidity	0.96**
Org. C	-0.96**
Clay content	0.81*

** - Significant at 1% level, * - Significant at 5% level

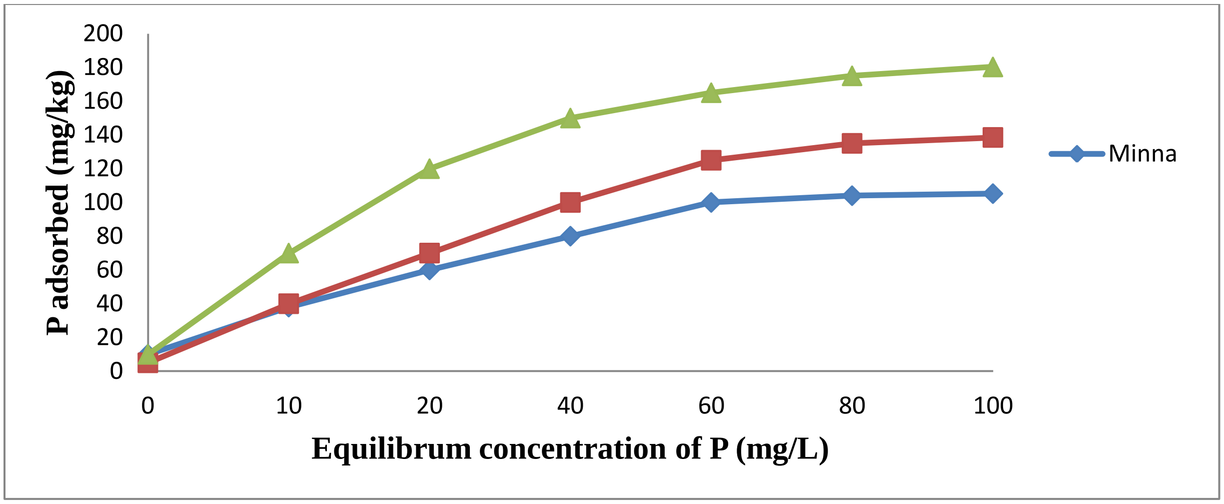

Fig.1. Phosphate adsorption isotherm of three soil series.

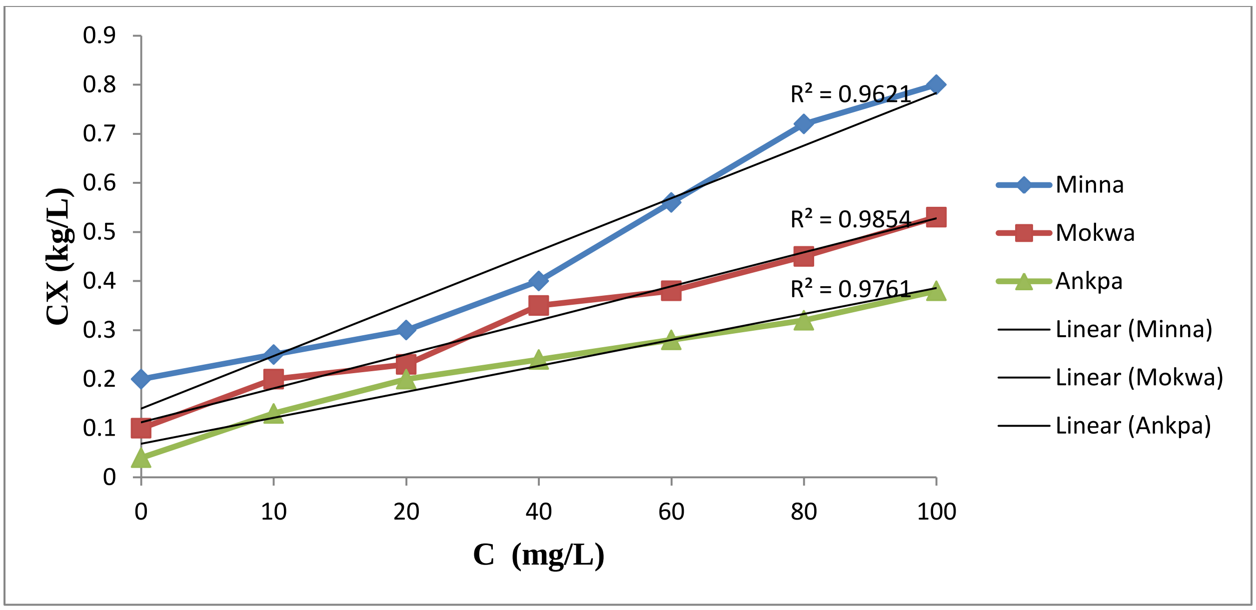

Fig.2. Langmuir isotherm for three soil series

CONCLUSION

The adsorption isotherm showed different curves for each of the three soil series. The order for P adsorption followed a decreasing trend of Ankpa > Mokwa > Minna. Although the P adsorption capacities of these soil series were generally low, Ankpa soil required more P fertilization than other soil for optimum crop production. Management practices involving the use of organic materials and liming as a basis for P sorption reduction will be useful for crop production in Nigeria especially in the agro ecology of the southern guinea savanna.

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