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PHOSPHORUS ADSORPTION CHARACTERISTICS OF SELECTED SOUTHEASTERN NIGERIAN SOILS

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ABSTRACT

The phosphorus adsorption characteristics of selected Southeastern Nigerian soils from Ikom, Bende and Ihiagwa were evaluated. P adsorption isotherm was obtained by shaking soil samples with 0, 10, 20, 30, 40 and 50 ppm P in 0.01M $CaCl_2$ solution. P adsorption maxima (b), affinity constant (k), buffering capacity and P sorbed at 0.2 ppm equilibrium solution were estimated. Also adsorbed P was correlated with some soil properties. The adsorption isotherm showed that the capacity to adsorb phosphorus varied in the order; Ikom> Ihiagwa> Bende. The values for the P sorbed at 0.2 ppm solution, buffering capacity, adsorption maxima and affinity constant were 43.28, 43.30, 34.48 and 12.95 ug/g *respectively for Ikom, 3.86, 7.78, 29.50 and 0.21* ug/g *respectively for Bende and 8.48, 10.00, 33.11 and 0.57* ug/g *respectively for Ihiagwa soils. The capacities to adsorb P was significantly and positively correlated with soil clay (r = 0.94), exchangeable aluminum (r = 0.72), soil pH (r = 0.83), whereas the correlation with exchangeable calcium (r = -0.56) and organic carbon (r = -0.72) were significantly negative. The implications are that the higher the soil pH, clay level, exchangeable aluminum, adsorption maxima and affinity constants the higher the soil adsorption capacities whereas the reverse will occur the higher the soil organic carbon and calcium levels. The study shows that Ikom soil will require higher P fertilization rates than the other two soils for optimum plant growth. Also management practices involving the use of organic matter and liming as basis for P adsorption reduction would be useful for improved crop production in these soils. The use of P adsorption isotherm as a valid tool for P fertilizer management is recommended for Southeastern Nigerian soils.*

INTRODUCTION

Soils of the humid tropics and indeed Southeastern Nigeria are acidic and contain appreciable mineral oxides (Hakim 2002, Opara-Nadi 1988). Under acid conditions, exchangeable iron and aluminum come into solution presenting some toxicity problems and causing the deficiency of nutrients especially phosphorus. The deficiency of phosphorus occurs through adsorption reactions making it one of the most limiting nutrients for food production in the region (Jubrin *et al* 2000).

Liming and application of phosphate fertilizers as organic or inorganic P forms have been suggested for the control of P deficiency problems in the soils (Opara-Nadi 1988). The rate of P application is estimated using chemical extractants together with some field and greenhouse calibration studies. The chemical extractants create solutions that dissolve phosphorus in amounts consistent enough to be correlated with crop P uptake (Howard 2004). Unfortunately when phosphorus fertilizers are added to the soil, only a small fraction comes into solution for crop utilization. A large proportion which is variable amongst soils is retained through adsorption reactions by the soil constituents. It has been estimated that about 70 to 80% of applied P is unavailable to coffee seedlings due to high adsorption by the soil (Famaye *et al* 2000). The concentration of soluble reactive P in soil and drainage water is thus controlled by rapid adsorption reactions (Siemens *et al* 2004).

Adsorption reaction affects phosphorus fertilizer use efficiency. The estimation of P, demands that allowance always be made for portion of soil P adsorbed by the soil constituents. This is necessary since adsorbed P is directly related to soil solution P (Agbede 1988). Phosphorus adsorption isotherm technique that uses the relationship between adsorbed P (capacity factor) and soil solution P (intensity factor) has been successfully used in predicting P requirement of crops in different soil systems (Agbede 1988). It is based on the principle that crop P requirement is directly related to the amount of P sorbed at a critical supernatant solution P known to be non - limiting to plants. This critical solution P concentration has been arbitrarily suggested to be 0.2 *ppm* and when continuously maintained in solution can provide adequately for crop production (Nnadi and Haque 1985). The amount of P sorbed at the critical solution P concentration of 0.2 *ppm* or the standard equilibrium solution P concentration is an important statistic for comparing the phosphorus adsorption capacity of soils with varying buffering capacities (Nnadi and Haque 1985).

The phosphorus adsorption capacities of soils are influenced by many factors. These include the soil organic matter and clay contents, oxides of Fe and Al, sesquoxides, exchangeable Fe and Al and pH (Udo 1985, Hakim 2002). Some physiochemical properties of soils such as exchangeable Ca and Mg, texture, porosity, bulk density, hydraulic conductivity, pH and ionic strength of competing ions also affect soil adsorption capacity (Bubba *et al* 2003). It has also been reported that factors relating to soil, climate, crop and management influence soil P adsorption capacity (Amapu *et al* 2000). The effects of organic matter and pH are conflicting as P adsorption could be increased, decreased or not affected at all by their presence while the relationship with clay content, sesquioxides, physiochemical properties is to be consistently positively correlated (Bubba *et al* 2003).

Humid tropical soils vary in their ability to adsorb phosphorus. Very high P adsorption values of 1000 ug/g and above have been associated with Andepts and soils containing desilicated non crystalline materials (Nnadi and Haque 1985) while values as low as 132 ug/g are commonly reported for others in Southeastern Nigeria.

(Udo 1985, Agbede 1988 and Osodeke 1999). Though the use of P sorption isotherms have been used in estimating the crop P requirements in some soils of Southeastern Nigeria, information concerning the P adsorption characteristics of the soils is scanty. The aim of this work was to evaluate the P adsorption characteristics of representative soils of Southeastern Nigerian in order to encourage more efficient and profitable phosphorus fertilizer practice.

MATERIALS AND METHODS

Study Sites: Three sites, representative of the region and formed from three distinct parent materials were used. The locations, mineralogy, parent materials and classifications described by Udo (1985) are as follows:

Ikom: Located on Latitude 6^o 50'N and Longitude 8^o 15'E in the rainforest vegetation zone. Its climatic condition is humid with a bimodal rainfall pattern that peaks in July and September and a dry spell that lasts from the months of November to February. It has a mean annual rainfall of 2800 mm, mean daily annual temperature of 26^{o}C and a mean relative humidity of 83%. The cropping pattern consists of a cassava/yam intercrop based. Soil fertility restoration is through bush fallow system that lasts between 5-7 years. The use of mineral fertilizers is unknown or at best minimal.

The soil type is an Oxisol (USDA classification system) derived from basalt with kaolinite as the dominant clay mineralogy. Soils are well drained with deep red color and a moderately strong medium sub-angular blocky structure. There is also appreciable gravel content, probably from undecomposed basalt or deposition by erosion. Soils show evidence of earthworm activity. The topography is a gentle slope with an elevation of about 109 m above sea level. There is evidence of water erosion especially on the middle slope of the toposequence. The site contains appreciable quantities of materials deposited from road construction activities along the Ikom-Obudu highway.

Bende: Located on Latitude 5^o 42'N and Longitude 7^o 44'E. The climatic condition is humid on a rainforest agro-ecological vegetation type. Mean annual rainfall is about 2400 mm, mean annual daily temperature is 27^{o}C and mean annual relative humidity is 81 %. The cropping pattern is a well ordered row teak plantation of the Ministry of Forestry, Abia State. The cropping history consisted of a combination of swamp rice, cassava and yam. Rice cultivation was on swamp soils in the valley bottom or middle slope, while cultivation of cassava and yam took place on the crest and middle slope of the toposequence. Decomposition of accumulated forest litter and mineral fertilizers were used to enhance soil fertility.

The soil type is an Inceptisol (USDA soil classification) on shale parent material and dominant smectite clay mineralogy. The color is dark grayish brown with mottles and a weak crumby structure. There was evidence of earth worm activity and termite mounds. Soil is poorly drained and on elevation of 85 m above sea level. The topography is undulating.

Ihiagwa: Lies on Latitude 5^o 21'N and 7^o 15' E in the humid rainforest agro-ecological zone. The mean annual rainfall is about 2019 mm, annual daily temperature of 28^{o}C and a mean relative humidity of 78%. Its cropping pattern is predominantly cassava based, with few scattered wild palms. The cropping history is dominated by cassava/maize intercrop with limited inorganic fertilizer use. The practice of bush fallow of 5 years average length was used for fertility restoration.

The soil type is an Ultisol (USDA classification system) derived from coastal plain sand and having kaolinite as the dominant clay mineralogy. Soil color is dark brown with a weak fine granular structure. Earthworm activity is evident. It is well drained and on a flat topography of elevation of 91 m above sea level.

Sampling Procedure: 36 soil samples were collected from 0-15 cm, 15-30 cm and 30-60 cm soil depths, and air dried, sieved to pass through the 2 mm diameter sieve and the fine earth fraction used for physical and chemical analysis. Particle size distribution was determined using the hydrometer method (Bouyoucos 1962), pH in 1:1 soil/ water suspension ratio was estimated using a Beckman pH meter, organic carbon by Walkley and Black wet oxidation method (Allison 1965) and value converted to organic matter by multiplication using a factor of 1.72, exchangeable calcium was determined in 1 N ammonium acetate extract using a flame photometer, exchangeable aluminum in 1N KCL solution by titration (Yuan 1959) and available P using Bray -1 solution (Jackson 1958).

Phosphorus Adsorption Studies: Phosphorus adsorption isotherm was obtained for the 0-15 cm soil depth using the method described by Fox and Kamprath (1970). 30 ml aliquots of 0.01M $CaCl_2$ solution containing KH_2PO_4 at P concentrations of 0, 10, 20, 30,.40 and 50 *ppm* were added to 3 g samples of soils in 50 ml centrifuge tubes. Two drops of toluene to prevent microbial growth were added and the samples shaken in a reciprocating shaker twice daily for six days (time required for the attainment of equilibrium). After equilibration, the samples were centrifuged and the P in the equilibrium solution determined by the Murphy and Riley method (1962).

Calculations: i. The amount of P remaining in solution was taken as the equilibrium concentration (c) and expressed as ug P ml^{-1}. The difference between the initial concentration and the equilibrium concentration was taken as the adsorbed P per unit of soil (x/m) and expressed in μgPg^{-1} soil.
ii. The adsorption isotherm of x/m verses c was plotted for each soil studied to obtain a straight line with slope of 1/b and intercept of 1/kb.
iii. In order to obtain adsorption capacities and the constants related to the bonding energy, the following form of Langmuir equation was used thus: $C/(x/m) = 1/kb + c/b$; where c = P concentration in equilibrium solution, X/m = P adsorbed by soil (ug/g), b = adsorption maximum (ug/g), k = a constant related to the bonding energy of the soil for P or affinity constant.
iv. To obtain the relationship between soil properties and adsorbed P, the adsorption maximum and bonding energy were correlated with some soil characteristics (exchangeable Ca, Al, pH, clay content and organic matter).

RESULTS AND DISCUSSIONS

Physico-chemical Characteristics of Sites: Selected physical and chemical properties of the soils studied are

Table 1: Some physical and chemical characteristics of the soils

Location	Depth (cm)	Sand	Silt	Clay	Organic matter	Exchangeable Ca	Exchangeable Al	pH H_2O	Avail P (ppm)
Ikom	0-15	58	5	37	1.1	1.3	4.0	4.9	0.6
	15-30	58	5	37	0.3	0.9	4.2	4.9	0.6
	30-60	59	8	33	0.2	0.4	4.2	4.9	0.5
Bende	0-15	79	8	13	1.8	8.6	0.4	4.6	2.4
	15-30	71	11	18	1.6	8.1	5.2	4.3	2.2
	30-60	69	9	22	1.2	5.4	8.0	4.2	1.2
Ihiagwa	0-15	94	1	5	1.2	0.9	1.6	4.8	1.5
	15-30	92	2	6	1.10	0.4	3.4	4.8	1.3
	30-60	92	1	7	1.06	-	0.4	2.0	4.8

Avail P = Available P

Table 2: Adsorption isotherm data for Ikom (IK) and Bende (Be) soils

S/n	Co C Um ml-1 UM ml-1	X umg-1	Log X	Log C	I/X	I/C	C/X
1	Ik = 0.03	9.97	1.00	-1.52	0.10	33.33	0.003
	Ih = 0.65	9.35	0.97	-0.19	0.11	1.54	0.07
	Be = 0.55	9.45	0.92	-0.23	0.11	1.82	0.06
2	Ik = 0.17	19.03	1.28	-0.77	0.05	5.88	0.01
	Ih = 1.24	18.76	1.28	0.09	0.05	0.81	0.07
	Be = 2.56	17.44	1.24	0.41	0.06	0.39	0.15
3	Ik = 0.70	29.30	1.47	-0.15	0.03	1.43	0.02
	Ih = 1.57	28.43	1.45	0.20	0.04	0.64	0.06
	Be = 2.71	27.29	1.44	0.43	0.04	0.37	0.10
4	Ik = 1.30	38.70	1.59	0.11	0.03	0.77	0.05
	Ih = 2.63	37.37	1.57	0.42	0.03	0.38	0.07
	Be = 3.02	36.98	1.57	0.48	0.03	0.33	0.08
5	Ik= 2.98	47.02	1.67	0.47	0.02	0.34	0.06
	Ih = 3.65	46.35	1.67	0.56	0.02	0.27	0.08
	Be= 5.75	44.25	1.65	0.76	0.02	0.17	0.13

Co = Initial P concentration C = Equilibrium P concentration X = P adsorbed = 10(Co-C)

presented in Table 1. Percentage clay content ranged from 5% to 37% with Ikom having the highest value. Texture varied between sandy clay loam and sandy in Ikom and Ihiagwa, respectively, with distribution being consistent down the depths whereas the distribution in Bende was loamy sand (0-15 cm), sandy loam (15-30 cm) and sandy clay loam (30-60 cm depth). The variation in texture reflected the differences in parent materials. Ezenwa (1987) observed that parent material is a major factor determining the texture of soils. Soil texture, especially clay content, affects soil behaviors, fertility, water and nutrient holding capacities as well as plant root movement (Esu 1987).This indicates that Ikom with high clay content would probably hold more water and nutrient and affect plant root movement than the other two soil types. It would also have high P fixing capacity (Enwezor *et al* 1990).

Organic matter reflects the level of soil fertility in the tropics (Opara-Nadi 1988).The values for the soils were low and decreased with depth. Available phosphorus followed the same trend as the organic matter. The bulk of the available P in these soils was usually in the organic P pools. The order for pH was Ikom > Ihiagwa > Bende. However, the values are only marginally different, all fall within the narrow range of 4.6-4.9. Exchangeable calcium was always higher in the surface soil layers than in subsoils. As commonly observed in soils of the tropics the surface soil layers were much more fertile than the subsoils (Oti 2002; Mbagwu 1992). The relative soil values for surface soil were 100:15:10, for Bende, Ikom and Ihiagwa soils, respectively. For calcium concentrations, relative values were 100:61:68 for Bende, Ikom and Ihiagwa soils respectively. Barring the presence of other major fertility constraints, the native inherent fertility status of the soils studied were ranked in the order Bende > Ikom > Ihiagwa.

Phosphorus Adsorption: A linear form of the P adsorption isotherm consisting of the amount of adsorbed P

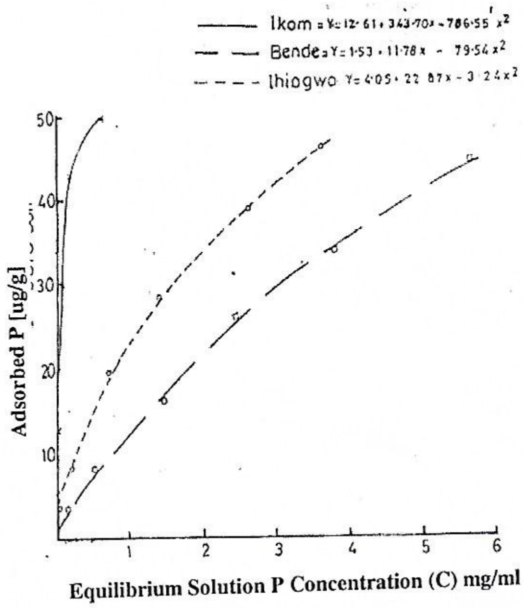

Fig. 1: Phosphorus adsorption isotherm for Ikom, Bende and Ihiagwa soils in 0 -15 cm depth

(x/m) (Table 2) against the equilibrium P concentration (c) for the soils is presented in Fig. 1 and indicates variations in their capacities to adsorb phosphorus. The curvilinear pattern of the curves shows that the capacities to adsorb phosphorus decreased with increasing equilibrium P concentration. Slope is steeper in Ikom than in Bende and Ihiagwa soils suggesting that the buffering capacity is higher in Ikom than in the other soils. The buffering capacities were 43.3, 10.0 and 7.8 ug/g for Ikom, Ihiagwa and Bende soils, respectively (Table 3). The standard P requirements defined as the P adsorbed at a standard P concentration of 0.2 ppm were 43.2, 8.0 and 3.0 ug/g for Ikom, Ihiagwa and Bende soils, respectively. The standard P requirement has been suggested as an important statistic for comparing soils of varying properties (Nnadi and Haque 1985). When marched against the scale proposed by Juo and Fox (1977), the soils studied fall within the low (Ikom) and the very low P adsorption scales. Similar observations have been reported for some Ghanaian soils (Owusu-Bennoah and Aqcuaye 1989), and soils of the forest zone of Southwestern Nigeria (Osodeke 1999).

Table 3: Adsorption constants (b and k), P adsorbed at 0.2 ppm equilibrium solution and Buffering Capacity of the soils

Location	Equilibrium Con. Range [ug/g]	Adsorption maxima (b)	Affinity constant (k)	0.22 ppm P	Buffering Capacity [ug/g]
Ikom	0-0.2	34.5	29.0	43.3	43.3
	0.2-3.0	38.6	12.9	-	-
Bende	0-0.6	29.5	1.7	3.9	7.8
	0.6-6.0	78.7	0.2	-	-
Ihiagwa	0-1.2	33.1	3.6	8.5	10.0
	1.2-3.6	66.7	0.6	-	-

When the adsorption data was plotted according to the Langmuir equation (Fig. 2), two distinct linear portions of the isotherms were obtained for the soils at different equilibrium concentration ranges. Similar observations have been reported by other workers (Udo 1981; Nnadi and Haque 1985; Owusu-Bennoah and Acquaye 1989).

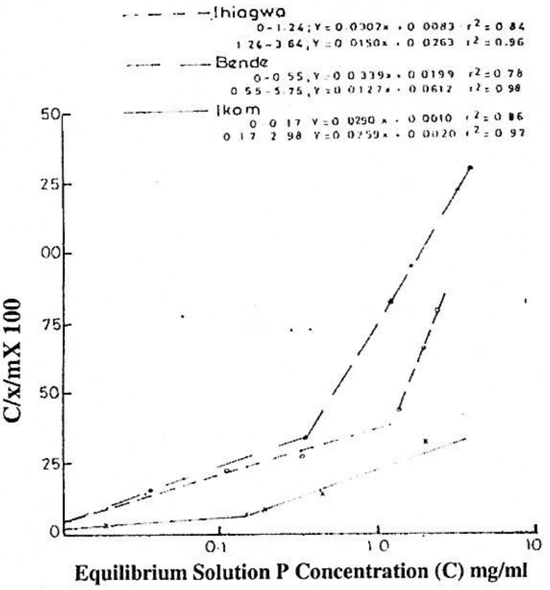

Fig. 2: Langmuir adsorption Isotherm for Ikom, Bende and Ihiagwa in 0-15 cm soil depth

The existence of at least two linear portions in the isotherm may be common in soils and indicates two distinct populations of adsorption sites with widely different affinities for P, the sites for adsorption at lower equilibrium P concentration having higher affinity for P than those associated with adsorption at higher equilibrium concentration (Udo 1981). He also proposed an increase in total negative potential at the surface due to adsorbed phosphate and increased interaction between adsorbed molecules as possible explanation for this phenomenon. The population of adsorption sites in the first linear portion of the soils existed in the equilibrium concentration range of 0 - 0.2, 0 -1.2 and 0 - 0.6 ug/ml for Ikom, Ihiagwa and Bende, respectively. Similarly, the sites for adsorption in the second linear portion of the isotherm existed in the equilibrium concentration values of 0.2-3.0 ug/ml for Ikom, 1.2-3.6 ug/ml for Ihiagwa and 0.6-6.0 ug/ml for Bende soil.

The existence of the two distinct portions shows that the soils will have two adsorption maxima (b) and affinity constants (k). The values for b and k are presented in Table 3 and are calculated from the regression equations of the two linear portions of the curves. It has been suggested that the adsorption capacity based on the population of sites in the first linear portion or low equilibrium solution P concentration is more important than that at the second linear portion since these are levels commonly reached when soils are fertilized with phosphorus for crop production (Udo 1981). The adsorption maxima at low equilibrium solution P concentrations varied between 29.5 to 34.5 ugP/g (Table 3). These values fall within the low ranges obtained for some tropical savanna soils of Western Nigeria (Osodeke 1999), as compared with higher ranges obtained for some Columbian soils (Le Mare and Leon 1989), and moderate when compared with values reported for Northeastern Nigerian soils (Kwari and Batey 1991). The capacities to adsorb phosphorus as indicated by the adsorption maxima (34.5, 33.1 and 29.5 ug/g) at low equilibrium P concentration for the soils vary in a decreasing order of Ikom>' Ihiagwa> Bende. Similarly the adsorption capacities as indicated by the adsorption maxima (38.6, 66.7 and 78.74 ug/g) at high equilibrium P concentration vary in a decreasing order of Ihiagwa> Bende>Ikom. The large values of the adsorption maxima in Bende and Ihiagwa compared to Ikom soil at the high equilibrium P concentration could be attributed to the existence of more population of adsorption sites in the former than the later soils.

The affinity constant factor related to the bonding energy (k), varied in a decreasing order of Ikom> Ihiagwa>Bende. The values for the first and second linear portions of the isotherms are 29.0 and 13.0 for Ikom soil, 1.7 and 0.2 for Bende soil and 3.6 and 0.6 for Ihiagwa soil. The high values in the first than the second linear portions indicate that adsorbed phosphorus would be held more tenaciously at low than high equilibrium P solution concentration ranges. Similar observations have been reported for some Nigerian soils (Udo 1981). The variations in the adsorption maxima (b) and affinity constant (k) could be related to the soil parent materials.

The capacities to adsorb phosphorus are affected by soil properties, especially the clay content, organic matter content, exchangeable aluminum, exchangeable calcium and soil pH. The influence of these properties at low equilibrium solution P concentrations constitutes the level reached when fertilizer P is applied to the soil and is considered. The relationship between the P adsorption capacity, represent the 0.2 ppm equilibrium solution P concentration, and the clay content for the soils is conflicting. While Ikom soil with the highest clay content (37%) than the other soils (13% for Bende and 1% for Ihiagwa) has the largest adsorption capacity (43.5 ug/g), Bende soil with higher clay content than Ihiagwa has the least adsorption capacity. There was a significantly positive correlation (Table 4) between clay content and the adsorption capacities.

Table 4: Correlation between soil properties, Langmuir constants and 0.2 ppm P for 0-15 cm-soil depth

Soil type	Soil properties	Langmuir constants b	Langmuir constants k	0.2 ppm P
Ikom [12]	Clay soil	0.50 ns	0.96**	0.94**
	% OC			
	Exchangeable Al	0.86**	0.94**	0.97**
	Exchangeable Ca	-0.91**	-0.48ns	-0.55ns
	PH	0.98**	0.79*	0.83**
Bende [12]	Clay content	0.50ns	0.96**	-0.94**
	%OC	-0.97**	0.66ns	-0.72*
	Exchangeable Al	0.86**	0.94**	0.97**
	Exchangeable Ca	-0.91**	-0.48ns	-0.56ns
	PH	0.97**	0.71*	0.77*
Ihiagwa [12]	Clay content	0.50ns	0.96**	0.94**
	%OC	-0.97**	0.66ns	0.72*
	Exchangeable Al	0.86**	0.94**	0.97**
	Exchangeable Ca	-0.91**	-0.48ns	0.55ns
	PH	0.98**	0.78**	0.82*

*** - Significant at 1% level,* - Significant at 5%, ns-non significant at 5% level,; No. of sample in parenthesis*

The influence of the clay content on the adsorption capacity could be related to the soil parent materials and mineralogy. Soils derived from basic rocks or basalts have high adsorption capacity while soils containing smectite have low adsorption capacities (Udo 1985). Ikom soil derived from basalt had the highest adsorption capacity while Bende soil with higher clay content than Ihiagwa soil but containing smectite in its mineralogy had the least capacity to adsorb P. The regression coefficient (Table 5) indicates that less than 26% of the effect of clay content on soil adsorption capacity can be interpreted by the regression model.

The relationship between exchangeable aluminum and the soil adsorption capacity showed that as the exchangeable aluminum increased, the adsorption capacity also increased. The correlation was significantly positive with a correlation coefficient (r) of 0.86 for all the soils (Table 4). Similar observation has been reported for Nigerian soils and soils elsewhere (Udo 1985 and Bubba *et al* 2003). It has been suggested that the influence of iron and aluminum as P adsorbents may be through an exchange reaction where singly-coordinated hydroxyl groups on oxide surfaces (adsorption sites) are replaced by phosphate probably during formation of binuclear surface complexes (Bubba *et al* 2003). The R^2 values (Table 5) indicate that the regression equation can predict about 75% of the effect of exchangeable Al on the adsorption capacity of the soils.

There was a significant but negative correlation between organic matter and the soil adsorption capacities (Table 4). The decrease in P adsorption capacity with increasing organic matter content could probably be due to competition with Ca, Al and Fe ion present in organic matter or by the adsorption of organic matter into surfaces of minerals resulting in a competition with phosphorus for adsorption sites (Hakim 2002). The regression equations for all the soils (Table 5) show that the regression model can predict more than 93% of the effect of organic carbon on the adsorption capacity of the soils.

Table 5: Regression analysis of Adsorption capacity (Y) and soil properties (X)

Soil type	Soil property	Regression equation	R^2
Ikom [12]	Clay content	$Y = 31.2 + 0.26X_1$	0.25
	%OC	$Y = 42.0-7.13X_2$	0.93
	Exchangeable Al	$Y = 29.8+1.25X_3$	0.75
	Exchangeable Ca	$Y = 34.4-0.56X_4$	0.82
	PH	$Y = 18.8X_5 - 57.31$	0.82
	K (affinity constant)	$Y = 31.2 + 0.26X_6$	0.50
	0.2 ppm P	$Y = 30.6 + 0.09X_7$	0.57
Bende [12]	Clay content	$Y = 31.2 + 0.05X_1$	0,10
	%OC	$Y = 41.0 - 0.52X_2$	0.97
	Exchangeable Al	$Y = 29.9 + 11.14X_3$	0.67
	Exchangeable Ca	$Y = 33.9 - 0.51X_4$	0.94
	PH	$Y = 18.25 - 54.5X_5$	0.95
	K (affinity constant)	$Y = 31.2 + 0.22X_6$	0.35
	0.2 ppm P	$Y = 30.7 + 0.08X_7$	0.44
Ihiagwa [12]	Clay content	$Y = 31.3 + 0.09X_1$	0.25
	%OC	$Y = 42.4 - 7.53X_2$	0.92
	Exchangeable Al	$Y = 30.1 + 1.18X_3$	0.70
	Exchangeable Ca	$Y = 4.4 - 0.57X_4$	0.78
	PH	$Y = 18.9 - 57.9X_5$	0.95
	K (affinity constant)	$Y = 31.49 + 0.2X_6$	0.46
	0.2 ppm P	$Y = 30.9 + 0.09X_7$	0.53

X_1 = clay content. *X_2 = %OC, X_3 = Exch. Al, X_4= Exch. Ca, X_5= PH, X_6 = K (affinity constant), X_7 No. of sample in parenthesis*

The relationship between soil pH and adsorption capacity shows that as the pH increased the soils adsorption capacity also increased. The values for the pH were 4.9, 4.6 and 4.8 while the adsorption capacities were 43.3, 3.9 and 8.5 for Ikom, Bende and Ihiagwa soils respectively. There was a significant and positive correlation between the soil pH and adsorption capacity. The correlation coefficient for all the soils was 0.98. The linear relationship between pH and adsorption capacity has been reported by other workers and could be due to the precipitation of exchangeable Al as hydroxyl-Al polymers which are thought to form new phosphate adsorbing surfaces in the soil (Hakim 2002). The regression coefficients (R^2) were 0.96, 0.94 and 0.94 for Ikom Bende and Ihiagwa soils (Table 5) indicating that the regression model can predict more than 90% of the effect of soil pH on the soils adsorption capacity.

Exchangeable calcium was negatively correlated with soils adsorption capacity. Similar observation has been reported for Nigerian soils (Udo 1985).

Summary and Conclusion: Phosphorus adsorption capacity of the soils decreased as more P fertilizer was added. Two populations of adsorption sites, one at low equilibrium P concentration and the other at high equilibrium P concentration control P adsorption in the soils. The order for adsorption followed a decreasing trend of Ikom > Ihiagwa > Bende. Generally, the P adsorption capacity for these soils was low, showing that little P fertilization was required for optimum crop production in the soils.

Soil properties particularly texture (clay content), exchangeable aluminum, pH, organic matter and exchangeable calcium affected the soils capacity to adsorb phosphorus. The greater the percentage clay content, exchangeable aluminum and pH, the higher the adsorption capacity whereas, the greater the organic matter and exchangeable calcium content, the lower the capacity to adsorb phosphorus. This showed that liming and use of organic matter are useful management practices for controlling P adsorption and hence fertilizer use efficiency in the soils. The use of phosphorus adsorption isotherm as a tool for efficient P fertilization in soils of Southeastern Nigeria is recommended.

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