PHOSPHORUS ADSORPTION ISOTHERMS OF SOME LOW ACTIVITY CLAY SOILS AS INFLUENCED BY SOIL PROPERTIES AND THEIR EFFECT ON FERTILIZER P RECOMMENDATIONS AND YIELD OF SOYBEAN (GLYCINE MAX (L.) MERR.) IN BENUE STATE, NIGERIA

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ABSTRACT: *The relationship between labile P sorbed to the soil surface and solution P can be described by a quantity-intensity relationship which shows P sorption or desorption as a function of P in the equilibrium solution. Twelve soils in Benue state representing Alfisols, Ultisols and Inceptisols were therefore used to examine the influence of soil properties on the shape and placement of their adsorption curves and yield of soybean. Sorption characteristics were determined in 0.01 M $CaCl_2$ solutions of various P concentrations. For each soil, the amounts of P that gave 0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1} solution concentrations were estimated from adsorption curves. In the greenhouse, 4 kg of soil from each location was placed in plastic pots. Amount of P estimated from sorption study was added as KH_2PO_4. The treatments were laid out in Randomized Complete Block Design (RCBD) and soybean seed variety (TGx 1448-2E) was planted and growth and development observed to maturity. Optimum solution P concentration (SPC) was determined for each soil in relation to yield. At harvest, SPC that gave highest grain yield was evaluated for each soil and the quantity of P required (SPR) to achieve this concentration was calculated. Consequently, Odoba would require highest P fertilizer application (604.84 Kg P ha^{-1}), (Tor-Donga 112.31, Abeda-Mbadyul 105.93) would require medium fertilization, (Utonkon 72.75, Katsina-Ala and Ofugo 67.64, Akoodo-Mbakor and Nor 61.26, Ogyoma 39.56, Otobi 33.18 and Abaji-Kpav 22.97 Kg P ha^{-1})would require low fertilization while Vanam (2.55 Kg P ha^{-1}) would require the least.*

KEYWORDS: Phosphorus; Adsorption; Isotherms; Growth; Fertilizer; Soybean; Soils

INTRODUCTION

A system has been used for predicting the quantity of phosphate fertilizer required to bring soil to various levels of adequacy for crop production. An approach to this problem has been suggested by (Beckswith, 1965) who measured adsorbed phosphate at standard supernatant concentrations of P as an estimate of phosphate needs of soils. Phosphate adsorption isotherms have been used as a basis for evaluating the P requirements of soils (Adetunji, 1997; 1995; 1994; Van Der Zee *et al.,* 1987). Adsorption isotherms have advantage over conventional methods of soils testing, because the sorption isotherms encamps both intensity and capacity factors (Rajan, 1975).

The relationship between labile P sorbed to the soil surface and solution P can be described by a quantity-intensity relationship or Q/I plot, which shows P sorption or desorption as a function of P in the equilibrium solution. The shape of the curve reflects the P sorption capacity and the slope of the curve reflects the buffering capacity for freshly added P. The shape and placement

of the Q/I plot depend on soil properties and P fertilization history (Bache and Williams, 1971). A common way to measure P sorption capacity in a soil is by construction of a sorption isotherm, which is the same as the Q/I plot.

Barrow (1974) and (Hartikainen, 1991) reported that sorption isotherms are normally made by equilibrating soil with a solution containing a known amount of P (batch process). After equilibration, soil and solution are separated by centrifugation and or filtration. Phosphorus in the solution is measured and the difference between initial P concentration and P in the equilibrium solution is assumed to be a measure of P sorbed or desorbed by the soil. This is repeated with increasing initial P concentrations. The phosphate concentration in solution (intensity) is measured and phosphate adsorbed (quantity) is calculated. The information so achieved is then summarized by plotting quantity against intensity. If this relationship is observed at a constant temperature, then the phenomenon is regarded as an adsorption isotherm.

In Nigeria, an estimated 50,000 hectares of Soybean, *Glycine max (L) Merr.* is cultivated annually, most of this being in Benue State (Aduayi *et al.,* eds. 2002). Farmers' yields average $300 – 1,030$ kg ha^{-1} of threshold grain. Under research conditions, yields of over 3000 kg ha^{-1} have been recorded. Higher yield values and better quality of the crop are probable if phosphate interaction in soils is well understood and properly managed as P is the limiting nutrient element for the production of this crop. The use of phosphate adsorption isotherms would predict the quantity of phosphate fertilizer required to bring soil to various levels of adequacy for soybean on soils of Benue state which are variously considered to be highly weathered with its attendant effect on phosphorus fixation thus avoiding waste as well as improving yield of the crop and reducing the cost of production. This is particularly so for soils of Benue state that have cation exchange capacity (CEC) values of less than 12.0 c mol kg^{-1} and are referred to as low activity clay soils.

This study was therefore undertaken with the objectives to:

1. Construct the phosphate adsorption isotherms of some low activity clay soils in Benue state, Nigeria from their adsorption data.

2. Estimate the amount of fertilizer P required for optimum growth and yield of soybean from these adsorption curves for the purpose of making fertilizer phosphate recommendations.

MATERIALS AND METHODS

The study involved laboratory and pot experiments. The laboratory experiment consisted of routine soil analysis and P sorption experiment.

Surface soil samples (0-20 cm) were collected from twelve bench mark soils in Benue State comprising four locations each from the soil classes of Alfisols, Ultisols and Inceptisols FDALR, (1990). All the sampled locations fall within the southern Guinea savannah zone of Nigeria.

The soil samples were air dried and passed through a 2 mm sieve for laboratory studies and pot experiment. Soil pH was determined by the glass electrode in a 1:2 soil: water ratio and in a 1:1 soil: KCl ratio suspensions. Particle size analysis was determined by the hydrometer

method of Bouyoucos, (1951), organic carbon by the chromic acid oxidation procedure of Walkley and Black, (1934). Exchangeable bases by the neutral ammonium acetate saturation. Sodium and K in the extracts were determined by the flame photometer while Ca and Mg were determined by the Atomic Absorption Spectrophotometer (AAS). Exchange acidity by the 1M KCl extraction and 0.01M NaOH titration. Nitrogen in the samples was determined by the macro- Kjeldahl method.

Phosphorus Sorption Study

This experiment was carried out in the Laboratory. Phosphate sorption characteristics of the soils were determined by placing eight separate 5 g sub- samples of the 2 mm size sieved soils in 50 ml polypropylene centrifuge tubes. Volumes of 40 cm^3 of 0.01 M $CaCl_2$ solution containing 0, 15, 25, 40, 100, 200, 400 and 800 mg l^{-1} P as KH_2PO_4 were distributed to the tubes as described by (Dear *et al.,* 1992). The samples were then shaken for 24 hrs and then centrifuged for ten minutes at 1200 rpm at 4°C in a refrigerated centrifuge. The supernatant was filtered through a Whatman's number 42 filter paper. Phosphorus in solution was determined by a modification of the Murphy and Riley method (Watanabe and Olsen, 1965) and reported by (Page *et al.,* 1982). A plot of P in equilibrium (supernatant) solution was constructed against the amount of P added. For each soil the amount of P that gave 0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1}, was estimated from these plots. Phosphate sorbed (Ps) was calculated as the difference between the concentration of the added P and P in solution

Pot Experiment

Four kg of the 2 mm sieved soil from each location was placed in each of the 33 plastic pots used in the pot study. For each soil the amount of P that was equivalent to the following levels of solution P concentration in the soils; 0.025, 0.05, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.225, 0.250 mg kg^{-1}, was added to the pots as KH_2PO_4 in 50 cm^3 of distilled water and mixed thoroughly. The amounts of P were estimated for each soil. All the pots initially received equivalents of 60 kg N ha^{-1} as urea, and 30 kg ha^{-1} K (Yusuf and Idowu, 2001) as KCl. There were pots without P addition that served as control bringing the total number of pots to three hundred and ninety six. Three soybean seeds of the variety TGX 1448-2E were planted per pot and later thinned to two and the pots were laid out in a Randomized Complete Block Design (RCBD) and the crop was grown to maturity with the normal agronomic practices carried out.

At harvest (12 WAP), the above ground plant material was dried and weighed. The plant materials were milled and digested in a 4:1 HNO_3:$HClO_4$ mixture and analyzed for P using the method of (Murphy and Riley, 1962). The optimum solution concentration was determined for each soil both in terms of grain and dry matter yield by subjecting the yield data to the analysis of variance. The critical equilibrium solution P concentration (SPC) was estimated as the amount of P in an equilibrium concentration needed to achieve maximum yield. The Standard Phosphate Requirement (SPR) was estimated as the amount of fertilizer P that gave the equilibrium solution concentration required to achieve maximum yield and the following Agronomic data were collected:

Dry matter yield at harvest, number of pods per plant, weight of seeds per pot

Statistical Analysis

Data generated in both the pot experiment was subjected to the analysis of variance. Means were separated using the Duncan multiple range test (DMRT). Regression analysis was carried out to study the relationship between the P sorbed and the logarithm of P concentration in the supernatant solution in the laboratory experiment. The SAS statistical package was used for these analyses.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Soils

Some selected properties of the soils studied are shown on Table 1. The result showed that the soils are acid ranging in pH (H_2O) from 5.5 at Abeda-Mbadyul to 6.3 at Nor. The pH (KCl) also varied from 4.2 at Odoba to 5.6 at Abeda- Mbadyul. The clay content varied widely with the Katsina-Ala soil having the least clay content of 3 % while Nor had the highest clay content of 26 %. Organic matter content of the soils varied from 0.98 % at Tor-Donga to 11.03 % at Otobi. Total nitrogen ranged from 0.03 % at Katsina-Ala and Abeda- Mbadyul to 0.3 % at Odoba. The soils are sand, sandy loam, loamy sand and sandy clay loam. Their ECEC also varied widely, ranging from 3.05 c mol kg^{-1} at Nor to 5.03 c mol kg^{-1} at Vanam.

It has been observed that soil texture is responsible for variation in phosphate adsorption behaviour. Fine textured soils adsorbed more phosphate than coarse textured soils. Such behaviour can be explained by the fact that fine textured soil exposes larger surface area than the coarse textured soils. The fine textured soils could also have stronger reactive sites than the coarse textured soils. Low affinity for P by sandy soils had earlier been reported by (Sibbenssen, 1981) higher P adsorption maxima were recorded with greater clay content of soils. The adsorption pattern observed at Utonkon, Nor, Ofugo could be partly attributed to this factor.

Variations in organic matter content, clay content, pH, phosphate added as fertilizer have been responsible for variations in P adsorption in soils,(Litaor *et al.,*2005; Brady and Weil, 2008). In the present study, variation could not be ascribed to such factors as pH as the pH of all the soils ranged between 5.6 and 6.3 with a very small difference and might have not affected the variation in phosphate adsorption to a greater extent. Similarly, phosphate added as fertilizers might have little effect as all the soils had no history of (phosphatic) fertilization. Variations in P adsorption between the soils could have been due to various reasons such as the initial P contents of the soils, their clay contents which could have provided the active sites for the adsorption, the organic matter content etc. In some cases, adsorption was higher in soils that had lower organic matter content as was observed at Nor, Ogyoma, Ofugo, Abaji-Kpav and Vanam. Holford and Patrick, (1979) however reported that lower adsorption in such surface samples might be owing to occupation of sites in the surface soils by organic anions. Adsorption at Odoba and Tor-donga could mostly be accounted for by the free oxide and clay content of these soils. The clay content at Odoba was more than three times the value obtained with the Otobi- Akpa soil and quite higher than what was obtained with the Abeda-Mbadyul soil. The total oxide content of the soils is also variable with the Tor-Donga soil having the highest value, followed by Otobi-Akpa while the least value was obtained with the soil from Abeda-Mbadyul. Amount of P adsorbed in this group of soils will be interplay between the clay content and the total oxides in the soils. (Agbenin, 2003), had earlier reported evidence

that clay mineral and extractable oxides of Fe and Al play an important role in P fixation in soils. In the same way, (Wiriyakitnateekul *et al.,* 2005) reported that in Thai soils, 81% of variability in P sorption was related with extractable Fe and Al by dithionate and oxalate extraction. Also, (Maguire *et al.,* 2001) reported that sorption of P was strongly correlated with the amounts of Al and Fe. In addition, (Wang *et al.,* 2001) mentioned that many soils with high P retention were related to high levels of oxalate extractable Fe and Al. variations in phosphate adsorption in these soils as affected by the soil properties ultimately affected and determined the shape of their adsorption curves. The acid pH of these soils favored the accumulation of these oxides. Formation of Fe-P compounds that are difficultly soluble could be responsible for this behavior. Various soil properties have been reported to be closely related to the P retention capacity of soils. Such properties include the extractable Fe and Al oxides (Toor *et al.,* 1997; Freese *et al.,* 1992), clay content (Johnston *et al.,* 1991; Toor *et al.,* 1997), organic C, pH (Barrow, 1974), calcium carbonate and sand content (Yuan and Lucas, 1982; Leclerc *et al.,*2001). Because of these close relationships, efforts have been made to predict P retention capacity from these soil properties using various combinations (Lookman *et al.,* 1996; Burt *et al.,* 2002; Ige *et al.,* 2003). Ige *et al.,* (2003) predicted P retention capacity of tropical soils from aluminum oxide, soil pH, and the clay content. Borling *et al.,* (2001) and (Maguire *et al.,* 2001) suggested the combination of iron and aluminum oxides for the prediction of soil P sorption capacity in non-calcareous soils.

Phosphorus Sorption Study

The sorption characteristics of the Alfisols indicate that the soils demonstrated some capacity to hold P. P sorbed in the Katsina-Ala soil (Q) increased with the concentration of added P (figure 1). However, the percentage of added P that was sorbed (Q (%) decreased as the concentration of added P was increased. The percentages of added P adsorbed were 93.98 %, 91.17 %, 81.93 % 82.49 % and 6.41% when 15, 25, 40, 100 and 200 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 400 mg P kg^{-1} (53.89 %) and 800 mg P kg^{-1} (59.38 %). The Utonkon soil demonstrated a higher capacity to hold P than the Katsina-Ala soil but the quantity of P sorbed also increased with the concentration of added P just as in the Katsina-Ala soil. The percentage of added P that was sorbed also decreased as the concentration of added P was increased. The percentages of added P adsorbed were 99.33 %, 92.17 %, 82.60 %, 83.49 % and 76.07 % when 15, 25, 40, 100 and 200 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 400 mg P kg^{-1} (62.98 %) and 800 mg P kg^{-1} (65.28 %).

The Akoodo-Mbakor soil demonstrated same capacity to hold P and P sorbed increased with the concentration of added P as well. The percentage of added P sorbed decreased as the concentration of added P was increased. The percentages of added P adsorbed were 95.33 %, 87.23 %, 75.51 %, 70.78% and 62.51 % when 15, 25, 40,100 and 200 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 400 mg P kg^{-1} (56.64 %) and 800 mg P kg^{-1} (54.69 %). The Nor soil demonstrated some high capacity to hold P and the quantity of P sorbed increased with the concentration of added P. The percentage of added P sorbed decreased as concentration of added P increased. The percentages of added P adsorbed were 99.20 %, 91.97 %, 82.94 %, 72.01 % and 69.72% when 15, 25, 40,100 and 200 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 400 mg P kg^{-1} (57.13 %) and 800 mg P kg^{-1} (59.90 %).

The same trend was observed with the Ultisols. In Ogyoma, the quantity of P sorbed also increased with the concentration of added P. However, the percentage of added P that was sorbed decreased as the concentration of added P was increased. The percentages of added P adsorbed were 99.31 %, 91.77 %, 80.93 %, 83.83% and 76.08 % when 15, 25, 40, 100 and 200 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 400 mg P kg^{-1} (69.68 %) and 800 mg P kg^{-1} (70.56 %).

The Ofugo, Abaji-Kpav and Vanam soil followed the same trend (figure 2).The percentage of added P that was sorbed decreased as the concentration of added P increased and the percentages of added P sorbed decreased significantly upon the addition of 400 and 800 mg P kg^{-1}.

Sorption isotherm of the Inceptisols is shown on figure 3 and follows the same trend as the other soils. In Abeda-Mbadyul soil, P sorbed increased with the concentration of added P and the percentage of added P sorbed decreased as the concentration of added P was increased. The percentages of added P adsorbed were 91.13 %, 82.69 %, and 69.08 % when 15, 25 and 40 mg kg^{-1} were added respectively. The percentages of added P sorbed decreased significantly upon the addition of 100, 200, 400 mg P kg^{-1} (57.77 %, 48.94%, 43.61 %,) and 800 mg P kg^{-1} (38.82%).

The same trend was observed with the Otobi-Akpa, Tor-Donga and Odoba soils. The quantity of P sorbed increased with the concentration of added P. However, the percentage of added P that was sorbed decreased as the concentration of added P was increased and decreased significantly upon the addition of 400 and 800 mg P kg^{-1}.

The graphic representation of adsorption isotherms of the twelve soils used in the study was obtained by plotting the quantity of adsorbed P by the soils against the equilibrium concentration of P in the supernatant solution. It is evident from these isotherms that each soil exhibited different adsorption characteristics. The adsorption isotherms however, can be clearly divided into three distinct regions. Some earlier researchers, (Bache, 1964; Muljadi *et al.,* 1966) and (Olsen and Khasawneh, 1980) have divided the adsorption isotherm into three portions. Somewhat similar trends were observed in the soils under study. In most of the soils, the curve rises up to some point, (140 mg kg^{-1} for Katsina-Ala, Utonkon, Odoba, Ofugo, Otobi and Abaji-Kpav). For Nor, the curve rises up to 100 mg kg^{-1}. In some soils such as Abeda-Mbadyul, Vanam and Tor-Donga, the rise is not very obvious probably due to the presence of limited sites for adsorption or the sites could have been occupied by organic anions. However, in all the soils, the adsorption isotherms obtained from plots of phosphate adsorbed against the different equilibrium concentrations could be conveniently divided into three regions corresponding to distinct stages in soil phosphate interaction as suggested by (Bache, 1964; Muljadi *et al.,* 1966) and (Olsen and Khasawneh, 1980). The first region corresponding to low phosphate additions resulting in practically complete adsorption or a negligible fraction of the added phosphate remaining in solution, causing the isotherm to rise steeply. The second region is the strongly curved portion of the isotherm. Bache, (1964) showed that adsorption in this region varies logarithmically with the equilibrium phosphate concentration. The third portion of the isotherm approaches linearity and occurs at medium to high phosphate concentration. Here, the adsorption varies linearly with the amount of phosphate in the equilibrium solution. At high level of this region, the slope of line is small and the isotherm, for most soils, tends to become more or less parallel to the X-axis.

Effect of P Solution Concentration on Mean Yield Data in the Pot Experiment

Effect of P Solution Concentration on Mean Yield Data in the Pot Experiment is shown on Table 2. The quantities of P in the supernatant soils solution required to achieve optimum yield range from between 0.025 mg kg^{-1} to 0.10 mg kg^{-1}. Vanam, Abaji-Kpav, Abeda-Mbadyul and Otobi-Akpa achieved optimum yield with a solution concentration of 0.025 mg kg^{-1}, this was followed by the Ogyoma soil that achieved optimum yield at solution concentrations of 0.05 mg kg^{-1}. Nor, Utonkon, Akoodo and Katsina –Ala soils achieved optimum yield production at solution concentrations of 0.075 mg kg-^{1}. Tor-Donga and Odoba soils achieved the same level of yield with a solution concentration of 0.10 mg kg-^{1}. It is worth mentioning that all the Alfisols attained optimum yield with solution P concentration of 0.075 mg kg-^{1} while the Ultisols and the Inceptisols could not attain their optimum yield with a uniform SPC value. The quantity of fertilizer P (SPR) required to achieve optimum yield in these soils would also follow the same trend as less fertilizer would be needed in those soils with smaller SPC values and vice versa. In terms of yield, the highest pod yield of 124 pods was obtained at Vanam with a seed weight of 41.27 g per pot and a dry matter yield of 31.90 g per pot. This yield values were followed by those obtained with the Abaji-Kpav, Abeda-Mbadyul and Otobi-Akpa soils that achieved optimum yield with the same solution concentration of 0.025 mg kg^{-1}.

The Ogyoma soil attained an optimum yield of 115 pods with a seed weight of 27.37 g per pot and a dry matter yield of 23.61 g per pot. The SPC of this soil is also lower than all these soils. Apart from the Tor-donga and Odoba soils that attained optimum yield levels at solution concentration of 0.10 mg kg^{-1}, all the other soils attained optimum yield at solution concentration of 0.075 mg kg^{-1}.

The SPC values were generally very low and variable, ranging from 0.025 mg kg^{-1} to 0.10 mg kg^{-1}. This is within the range reported by previous workers, though with crops other than soybean (Fox *et al.,* 2006 ; Adetunji, 1995; Adetunji, 1997) and higher than what was reported for maximum yield of maize by (Kang and Juo, 1979). The value of 0.2 mg kg^{-1} reported by (Beckswith, 1965) and widely used for West African soils (Udo and Dambo, 1979) is high for the production of soybean in soils of Benue state.

Plots of P added to the soils against P in the supernatant solution were used to estimate the amounts of fertilizer P that would be required to achieve the eleven levels that constituted the treatments. The variation observed in the sorption characteristics of the soils ensured that different amount of fertilizer P are required. On the whole the Ultisols required the least average amount of fertilizer P (7.12 g) to attain the eleven target solution concentrations and were followed by the Alfisols (9.68 g) while the Inceptisols with their variable requirement needed an average of 33.84 g to attain the target solution concentrations. This is equivalent to 604.85, 112.31 and 105.93 kg P ha^{-1} for Odoba, Tor-Donga and Abeda-Mbadyul respectively. This range of P fertilization is high.

Utonkon, Katsina-Ala and Ofugo, Akoodo and Nor would require 72.75, 67.64 and 61.26 kg P ha^{-1} respectively. Thus, the Alfisols and Ofugo would require medium fertilization.

Low fertilization would be required in Ogyoma (39.56 kg P ha^{-1}), Otobi- Akpa (33.18 kg P ha^{-1}), Abaji- Kpav (22.97 kg P ha^{-1}) while the Vanam soil would require the least P fertilization (2.55 kg P ha^{-1}).

CONCLUSION

It was concluded that:

1. Variations in P adsorption between the soils could have been due to various reasons such as the initial P contents of the soils, their clay contents which could have provided the active sites for the adsorption, the organic matter content etc.

2. These variations ultimately affected and determined the shape and placement of their adsorption curves.

3. The optimum soil solution concentration of P for soybean yield varied across the soils with the Vanam, Abaji-Kpav, Abeda-Mbadyul and Otobi-Akpa soils attaining optimum yield with a solution concentration of 0.025 mg P kg^{-1} soil, Ogyoma 0.05 mg P kg^{-1} soil, all the Alfisols as well as the Ofugo soil attained optimum yield with a solution P concentration of 0.075 mg P kg^{-1} soil. The Tor-donga and Odoba soils attained optimum yield with solution concentration of 0.10 mg P kg^{-1} soil.

4. Odoba, Tor-Donga and Abeda-Mbadyul would require 604.85, 112.31 and 105.93 kg P ha^{-1} respectively. This range of P fertilization is high.

5. Utonkon, Katsina-Ala and Ofugo, Akoodo and Nor would require 72.75, 67.64 and 61.26 kg P ha^{-1} respectively. Thus, the Alfisols and Ofugo would require medium fertilization.

6. Low fertilization would be required in Ogyoma (39.56 kg P ha^{-1}), Otobi- Akpa (33.18 kg P ha^{-1}), Abaji- Kpav (22.97 kg P ha^{-1}) while the Vanam soil would require the least P fertilization (2.55 kg P ha^{-1}).

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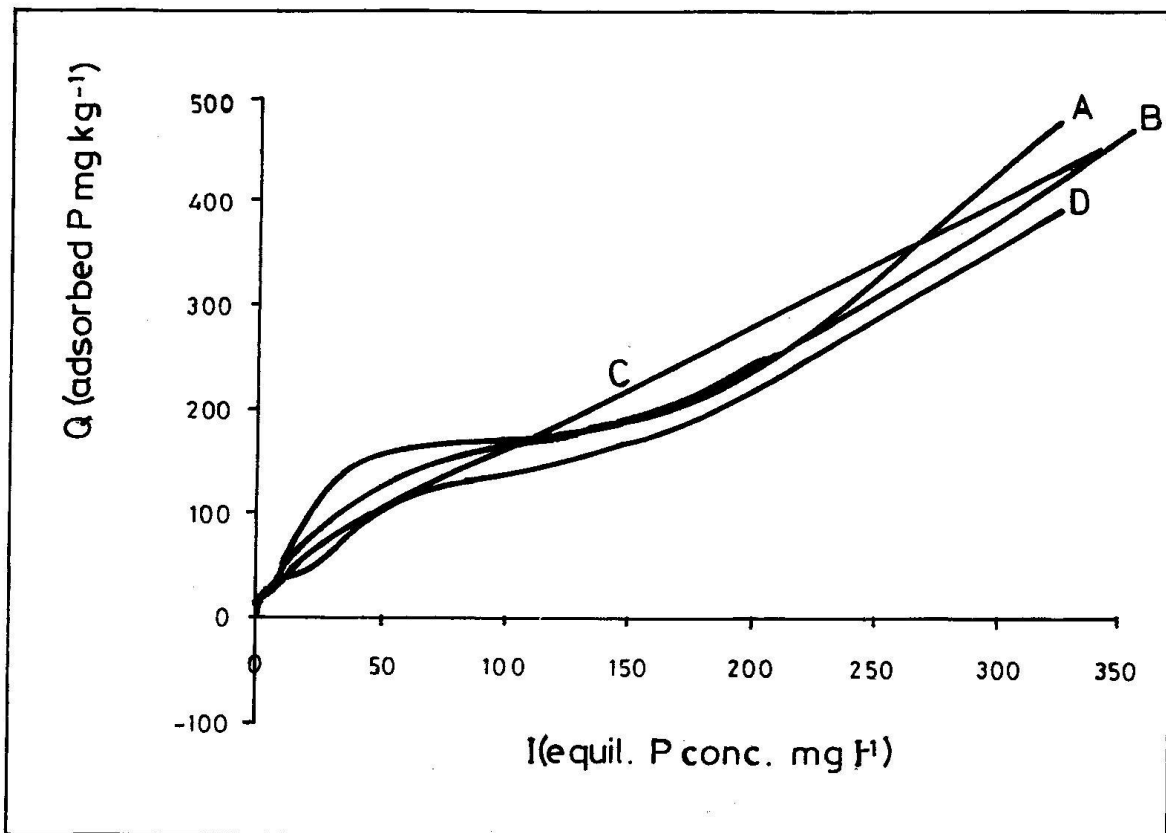
APPENDIX

Figure 1: Sorption isotherm for Alfisols

KEY:

 Isotherm A, Katsina- Ala soil

Isotherm B, Utonkon soil

Isotherm C, Akoodo-Mbakor soil
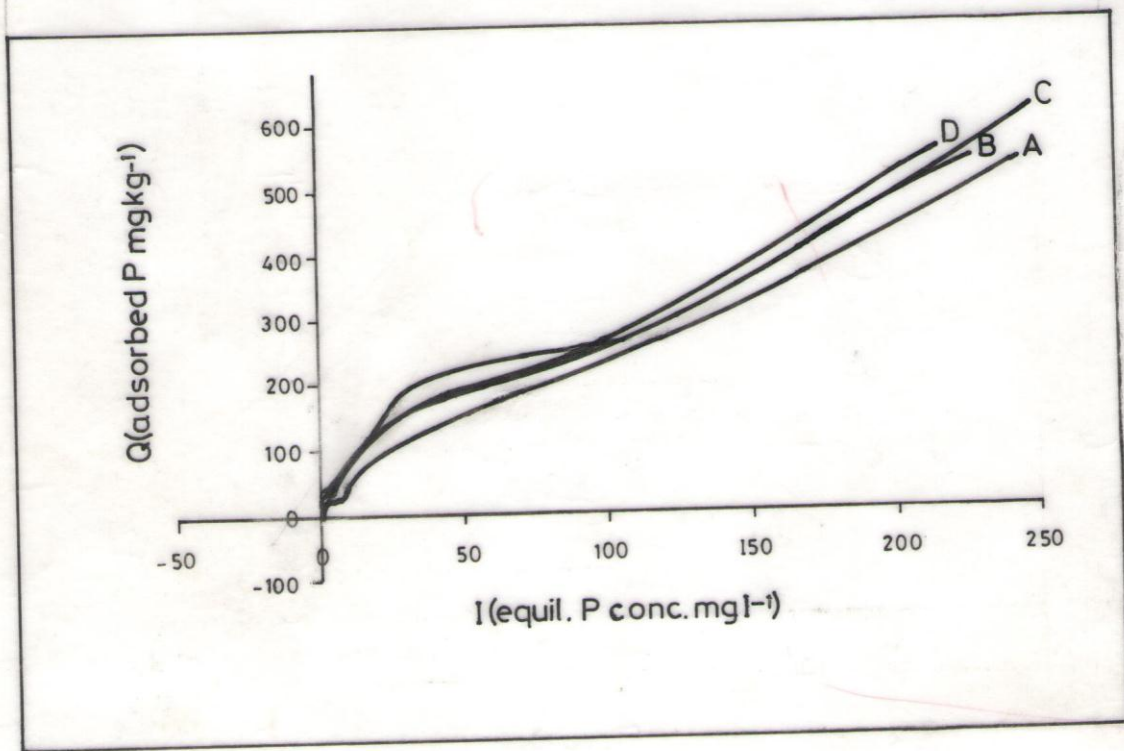
Isotherm D, Nor soil

Figure 2: Sorption isotherm for Ultisols

KEY:

 Isotherm A, Ogyoma soil

Isotherm B, Ofugo soil
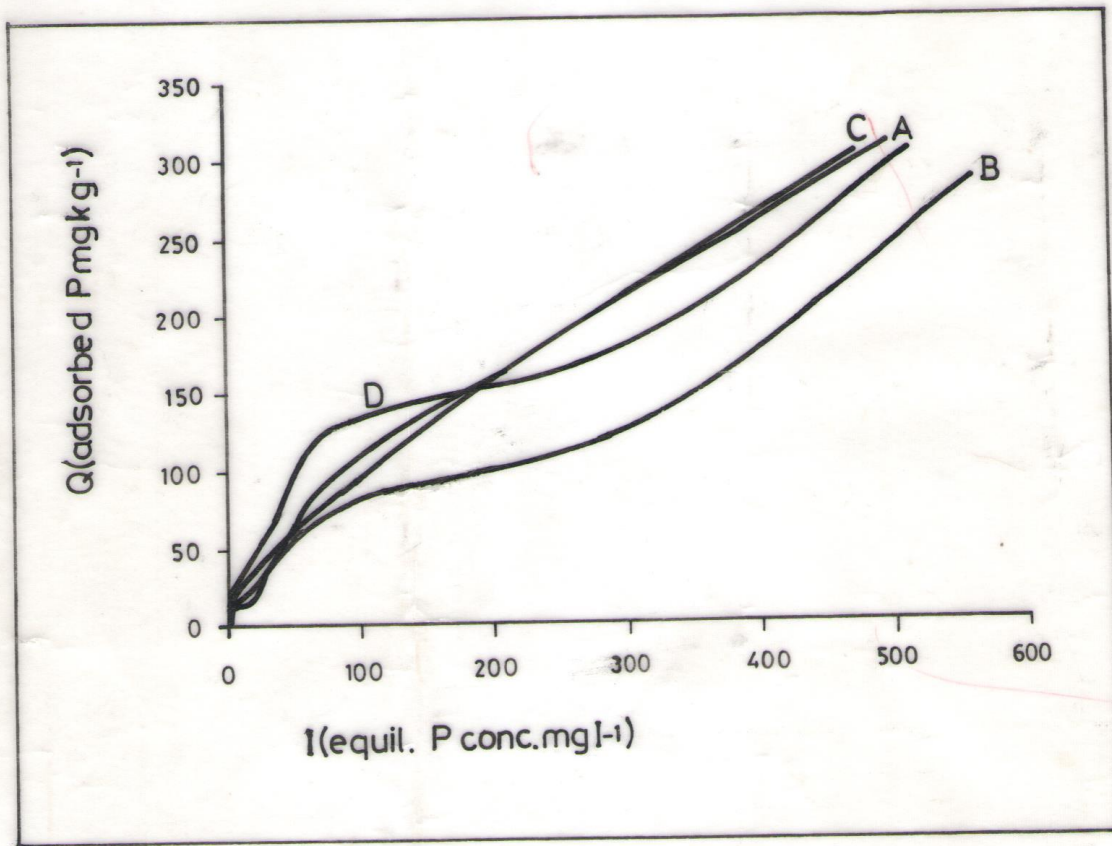
Isotherm C, Abaji-Kpav soil

Isotherm D, Vanam soil

Figure 3: Sorption isotherm for Inceptisols

KEY:

Isotherm A, Abeda-Mbadyul soil

Isotherm B, Otobi-Akpa soil

Isotherm C, Tor-Donga soil

Isotherm D,Odoba soil

Table 1: Some Properties of the Experimental Soils

Location	pH (H$_2$O)	pH (KCl)	Clay (%)	Textur	O.M (%)	Tot N (%)	K	Na ←	Ca (cmol	Mg kg^{-1})	E.acid	ECEC →	Fe$_2$O$_3$ (%)	Al$_2$O$_3$ (%)
K/Ala	5.8	5.2	3	S	1.22	0.03	0.24	0.12	2.03	0.77	0.03	3.18	0.8	0.7
Utonkon	5.7	4.9	16	SCL	1.6	0.06	0.41	0.22	3.05	1.02	0.02	4.72	0.9	1.2
Akoodo	5.9	5.2	10	LS	1.69	0.06	0.23	0.19	2.00	0.66	0.03	3.08	1.5	0.9
Nor	6.3	5.4	26	SCL	1.69	0.05	0.23	0.13	2.00	0.70	0.02	3.05	0.9	1.1
Ogyoma	5.9	4.9	9	L	2.13	0.09	0.26	0.13	2.07	0.78	0.02	3.26	1.2	0.9
Ofugo	5.8	5.5	11	LS	2.03	0.08	0.36	0.20	2.56	0.83	0.02	3.97	1.1	1.3
Abaji	6.0	5.1	12	LS	2.36	0.07	0.33	0.13	2.11	0.86	0.01	3.45	1.6	1.0
Vanam	6.0	4.8	6	SL	9.46	0.11	0.47	0.22	3.10	1.24	0.02	5.03	0.5	1.1
Abeda	5.5	5.6	9	SCL	1.07	0.03	0.24	0.12	2.00	0.78	0.01	3.14	0.6	0.8
Otobi	5.6	5.1	4	S	11.03	0.05	0.47	0.13	1.67	0.73	0.02	3.11	0.4	0.9
Tor-donga	5.9	5.3	17	SL	0.98	0.1	0.46	0.23	2.36	1.02	0.02	4.09	1.9	1.2
Odoba	5.7	4.2	12	LS	2.0	0.3	0.37	0.14	2.64	0.93	0.02	4.11	2.8	1.3

Table 2: Effect of P Solution Concentration on Mean Yield Data in the Pot Experiment

LOCATION	K/ALA	UTONKON	AKOODO	NOR	OGYOMA	OFUGO	ABAJI	VANAM	ABEDA	OTOBI	DONGA	ODOBA
SPC (mg kg^{-1})	0.075	0.075	0.075	0.075	0.050	0.075	0.050	0.025	0.025	0.025	0.10	0.10
POD.NO.	76.0	51.67	96.67	56.33	115.67	62.0	117.67	124.33	54.33	53.0	59.33	48.67
SEED WT. (g pot^{-1})	25.9	13.02	16.56	15.47	27.37	24.26	30.8	41.27	15.12	22.34	9.67	12.71
DMY (g pot^{-1})	17.26	14.35	7.55	16.45	23.61	16.45	23.21	31.90	14.99	16.30	13.88	8.17