NIGER AGRIC. J. 36 (2005)157-168

ESTIMATION OF PHOSPHORUS REQUIREMENT OF MAIZE (ZEA MAYS) IN SELECTED SOILS OF SOUTHEASTERN NIGERIA USING P-SORPTION ISOTHERM

Uzoho, B. U. and Oti, N. N.
Department of Soil Science and Technology,
Federal University of Technology Owerri,
P.M.B.1526 Owerri, Imo State Nigeria.

ABSTRACT.

The Phosphorus requirement of maize (Zea mays) from selected Southeastern Nigerian soils formed from three different parent materials [Ikom (Lat 6° 50′ N, 8° 15′E), Bende (5° 42′ N, 7° 44′ E) and Ihiagwa (5° 21′ N, 7° 15′ E)] were estimated using the P sorption isotherm. Soil samples were shaken in graded solutions of P (0, 10, 20, 30, 40, and 50 ppm P), and the P sorbed at 0.2 ppm equilibrium solution P concentrations and that required to saturate the adsorption complex of the soils were estimated from the sorption isotherm. Maize was grown in polyethylene bags and four P rates representing: (1) Control, (2) P required to attain 0.2 ppm equilibrium solution P concentration (3) P required to saturate the adsorption complex plus 26 kg P/ha (usually recommended P rate for maize fertilization in Southeastern Nigerian soils) and (4) P required to saturate the adsorption complex plus 22 kg P/ha (10 kg P_2O_4/ha less than the usually recommended P rates) were added. The polyethylene bags were arranged in a randomized complete block design with four replications. The P sorbed at 0.2ppm equilibrium solution concentrations were 103 ug/g P for Ikom, 9 ug/g P for Bende, and 19 ug/g P for Ihiagwa . The P required to saturate the adsorption complex of the soils were 30 kg/ha, 4 k/ha and 9 kg/ha for Ikom, Bende and Ihiagwa soils respectively. The P fertilizer rates required for optimum maize production in the soils were 52 kg/ha, 9 kg/ha and 31 kg/ha for Ikom, Bende and Ihiagwa soils respectively. The study shows that the capacity to sorb P in the soils is low in the order ; Ikom > Ihiagwa > Bende suggesting that only a small amount of P fertilizer should be required for optimum maize production in the soils. Organic matter and liming as management practices shall be useful for P fertilizer utilization in the soils. The use of P- isotherm technique for phosphorus fertilizer estimation is recommended for efficient P fertilization in Southeastern Nigerian soils.

Keywords: P sorption isotherm, P requirement, maize.

INTRODUCTION

Phosphorus is the second most important element after nitrogen for crop production. Its uptake is through the root and from the amount present in soil solution. The soil solution P concentration on the other hand depends on the amount of adsorbed P in the soil solid phase. The ability of the soil solid phase to replenish the solution P concentration as it is depleted during plant uptake is referred to as the soil buffering capacity (Bubba et al. 2003).

Soils of the humid tropics have widespread P deficiency (Adepoju 1985), making it one of the most limiting crop nutrients in the region (Jubrin et al. 2000). In estimating the P requirements in these P deficient soils, suitable chemical extractants are used the results obtained calibrated under field and green house experiments. These extractants estimate only the available P portion that is present in the immediate soil solution. In some efficient P fertilization programme, however estimation of crop P requirement should take into consideration both the solution P concentration and the adsorbed P fractions. This is necessary since the soil solution P is directly related to the soil solid P phase.

Phosphorus sorption isotherm a technique that uses the relationship between adsorbed P (capacity factor) and the soil solution P (intensity factor) has been successfully used in predicting the P requirement of several crops under different soil conditions (Osodeke 1999). Agbede (1988) suggested that P sorption isotherm could be an effective technique for determining the P fertilizer rates for crops on soils with both high and low capacities to sorb P, since the critical equilibrium P for different crops appear constant for a particular plant on soils of different P buffering capacities. Its use is based on the principle that P requirements are directly related to the amount of P adsorbed by soils at a critical supernatant solution P known to be none limiting to crops. This critical solution P has been suggested to be 0.2 ppm and when continuously maintained in solution culture or soil solution will provide adequately for crop growth on soils of different properties (Sardi and Csatho 2002). The choice of a 0.2ppm standard equilibrium solution concentration has however, been criticized, as fertilizer recommendation based on the value could be misleading since plant P requirements varies depending on crop types and soil characteristics (Udo 1985). Hence Paul and Fred (1993) suggested that plant fertilizer P recommendation should take into account the requirements of individual plants and soil conditions.

The P requirements of many crops in the tropics have been reported. Osodeke (1999) reported a P requirement of 0.3 ppm for rubber growth in forest soils of Southwestern Nigeria. Nnadi and Haque (1985) reported critical P requirements of 0.016 and 0.07 ppm for native clover crops in Ethiopian soils. Udo (1985) reported values of 0.3 ppm for sweet maize growth in savanna soils of Northern Nigeria.

Southeastern Nigerian soils vary considerably in their ability to sorb phosphorus. Information regarding the use of phosphorus sorption isotherm for predicting the P requirement of most arable crops is scarce. The main objective of this study is to estimate the P requirements of maize in selected southeastern Nigerian soils using the P sorption isotherm.

MATERIALS AND METHODS.

Study Sites:The study sites were Ikom on latitude 6° 50'N and longitude 8° 15'E and derived from basalt, with kaolinite clay mineralogy and Oxisol (USDA soil classification) soil type, Bende (latitude 5° 42'N and Longitude 7° 44'E) derived from shale with a smectite clay mineralogy and soil classification as Inceptisol (USDA soil classification) and Ihiagwa on Latitude 5° 21'N and 7° 15'E and formed from coastal plain sand with a dominant kaolinitic clay mineralogy and Ultisol soil type (USDA classification).

Sampling Procedure Soil samples were collected from 0-15 cm and 15-30cm depths, air dried, sieved to pass through 2mm diameter sieve and used for some physical and chemical analysis. Particle size distribution was analyzed using the hydrometer method (Bouyoucous 1962), pH in 1:1 soil/ water suspension ratio was estimated using the Beckman pH meter, organic carbon by Walkley and Black wet oxidation method (Allison 1965) and value converted to organic matter by multiplication using factor of 1.72, exchangeable cations were extracted in 1N ammonium acetate solution and exchangeable ca, k and Na determined in flame photometer while exchangeable Mg was determined by EDTA titration method (Heald 1965), exchangeable acidity in 1N KCL solution by titration (Yuan 1959) and available P using Bray 1 solution (Jackson 1958)

.Phosphorus Adsorption Studies. The method used is as described by Fox and Kamprath (1970). 30 ml aliquot of 0.01M $Cacl_2$ solution containing KH_2P0_4 at P concentrations of 0,10,20,30,40, and 50 ppm were added to 3g soil sample in 50ml centrifuge tubes. Two drops of toluene were added to suppress microbial growth and the samples shaken for 30 minutes in a reciprocating shaker twice daily for six days. After equilibration for six days, the samples were centrifuged and the P in equilibrium solution determined by Murphy and Riley method (1962). P adsorbed was calculated as the difference between added P and P in equilibrium solution.

Maize P requirement

Five kilograms (5 kg) of each soil type were weighed into polyethylene bags and the following four P rates added: 1. Control, 2. P adsorbed at standard equilibrium solution P concentration of 0.2 ppm (103, 9, 19 P kg/ha for Ikom, Bende and Ihiagwa soils, respectively), 3. P required to saturate soil adsorption complex of the soils (30, 4 and 9 kg P/ha for Ikom, Bende and Ihiagwa soils respectively) plus 26kg P/ha (usually recommended P rate for maize fertilization in S.E.Nigeria soils) (56, 29, 35 kg P/ha for Ikom, Bende and Ihiagwa respectively). 4. P to saturate soil adsorption complex plus 22 kg P/ha (10 kg P_20_5/ha less than usually recommended P rate for southeastern Nigerian soils) (52, 25, 31 kg P/ha for Ikom, Bende and Ihiagwa respectively). Nitrogen and phosphorus were also applied at equivalent rates of 120 kg N/ha and 60 kg K_20/ha. The fertilizers were thoroughly mixed with soils and the soils watered to field capacity.

Two maize seeds (Variety Farz 34) were planted and the bags arranged in a Randomized Complete Block design (RCB) with 4 replications.

The crops were grown for 9 weeks after which they were harvested and the roots

Thoroughly washed to remove adhering soil particles. The harvests were dried in the oven at 60°C and the dry matter yields determined. Some plant tissues were ground, ashed and the P content of the plants determined. The plant P use efficiency was estimated as the yield obtained from P (Yp) fertilized plots minus control (Yc), divided by a unit weight of the applied P fertilizer (Pw) (Kogbe and Adeniran 2003)

Statistical analysis.
Maize yield data was analyzed using ANOVA and means separated using LSD at 5% critical level. T he relationship between soil adsorption capacity and selected soil properties were examined using correlation analysis.

RESULTS AND DISCUSSIONS.

Physio-chemical characteristics of the soils.

Selected physical and chemical properties of the soils are presented in Table 1.

Table 1. Selected physical and chemical characteristics of the soils studied.

Name	Depth (cm)	TC	S	Si	C	O.M	AL^{3+}	H^+	BS	pH H_2O	Avail P (mg/kg)	Exch Ca	Na	k	Mg	CEC
			---% ---			---- g/kg ---------						----Cmol/kg I -----------				
IK	0-15	Scl	58	5	37	1.9	100	55	40	4.9	0.61	1.30	0.57	0.37	0.80	7.6
	15-30	Scl	59	5	37	0.6	62	44	40	4.9	0.56	0.90	0.37	0.40	0.10	6.7
BE	0-15	Ls	79	8	13	3.0	60	100	91	4.6	2.40	8.60	0.35	0.37	2.40	12.9
	15-30	Scl	11	18	18	3.0	100	8	63	4.3	2.20	8.10	0.31	0.51	2.40	18.0
IH	0-15	S	94	1	5	2.1	65	73	35	4.8	1.48	0.90	0.26	0.35	0.25	5.0
	15-30	S	92	2	5	1.9	65	100	18	4.8	1.31	0.44	0.43	0.21	0.06	6.0

IK = Ikom, BE = Bende, IH = Ihiagwa, Avail P = Available Phosphorus, TC= Textural class, Scl =Sandy clay loam, Ls = Loamy sand, S = Sand, C = Clay, Si = Silt, O.M = Organic matter, BS = Base saturation, Exch = Exchangeable, CEC = Cation exchange capacity.

Soil textures varied as Sandy clay loam, Loamy sand and sandy for Ikom, Bende and Ihiagwa respectively. The variation in texture reflects the differences in the parent materials. Ezenwa (1987) observed that texture of soils is greatly determined by the parent materials. Texture plays dominant role in soil behavior as it affects water and nutrient retention as well as suitability of soils as a rooting medium (Isirimah 1987). The pH of the soils is low and ranged from 4.6-4.9. Opara-Nadi (1988) observed that aluminium toxicity occurs in soils with pH values less than 5.5 and increases in severity as the pH decreases below 5.0. In soils of high acidity, the normal growths of plants are disturbed, yields are decreased and in extreme cases the plants die (Booklin 1996). The organic matter content, CEC and available P status were high in Bende relative to the other soils and followed the trend Bende > Ihiagwa > Ikom. The CEC and indeed fertility of the soils is related to the organic matter content. The values of the exchangeable bases also reflect the differences in the soil organic matter. Enwezor et al (1990) observed that the fertility of tropical soils is related to their organic matter content. 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 characteristics of the soils.

A plot of the amount of adsorbed P (x/m) against the equilibrium P concentration (c) for the soils is presented in figure I. The adsorption isotherms indicate the capacities of the soils to adsorb P. As the amount of P added increased, P adsorbed also decreased. The slope of the curves is steeper in Ikom soil than the other two soil types. This probably could be because of the high buffering capacity of the Ikom soil. The order for the buffering capacity is Ikom > Ihiagwa > Bende. Buffering capacities are affected by factors such as soil texture particularly clay content, CEC, and bulk density (Sardi and Csatho 2002). It could also be affected by the exchangeable aluminium content of the soil. The extent of their influence varies depending on the nature of the parent materials as well as the clay mineralogy (Siemens et al 2004). Ikom has the highest clay content of 37% and a relatively high exchangeable aluminium content, implying that the soil texture especially the clay fraction and exchangeable aluminium are the predominant factors controlling the buffering capacities of these soils since organic matter content and the CEC are very low. The correlation between buffering capacity and soil properties (Table 2) showed that clay content and exchangeable aluminium were positively and significantly correlated with buffering capacity while organic matter was negatively correlated. The correlation

indicate that as the clay and exchangeable aluminium content of the soils increased, the buffering capacity also increased while the reverse would apply for organic matter.

The amounts of P sorbed at equilibrium solution P concentration of 0.2 ppm were 43.3 ug/g, 3.7 ug/g and 8.5 ug/g for Ikom, Bende and Ihiagwa respectively. The P sorbed at 0.2 ppm equilibrium solution concentration or the standard P requirement has been suggested as important parameter for comparing the P adsorption capacity of different soils (Nnadi and Hague 1985). When continuously maintained in solution culture or soil solution, the 0.2 ppm equilibrium P concentration can provide adequately for crop P needs in soils of different buffering capacities (Siemens et. al. 2004). Several workers have used the

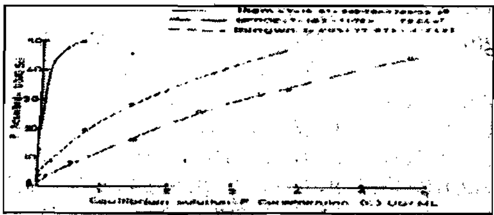

Fig: Adsorption of Phosphorus in Ikom, Bende and Ihiagwa soils

Table 2: Correlation between soil properties and buffering and adsorption capacity of the soils.

Soil type	Soil properties	buffering capacity	Adsorption capacity
Ikom	Clay content	0.93**	0.94**
	% Organic matter	-0.72*	-0.95*
	Exchangeable Al	0.86**	0.97**
	Exchangeable Ca	-0.91**	-0.83**
	CEC	0.51 ns	0.54ns
Bende	Clay content	0.91**	0.94**
	% Organic matter	-0.72*	-0.97*
	Exchangeable Al	0.86**	0.97**
	Exchangeable Ca	-0.91**	-0.83
	pH	0.97**	0.77*
	CEC	0.57ns	0.56ns
Ihiagwa	Clay content	0.91**	0.94**
	% Organic matter	-0.71*	- 0.94**
	Exchangeable Al	0.86**	0.97**
	Exchangeable Ca	-0.91**	- 0.83
	pH	0.98**	0.82*
	CEC	0.48ns	0.51ns

** - Significant at 1% level.
* - Significant at 5% level.
ns – non significant at 5% level

Standard P concentration for comparing the P adsorption characteristics of soils (Agbede, 1988; Osodeke and Omueti, 1995). When marched with the scale proposed by Juo and Fox (977), the soils fall into the low (Ikom) and very low (Bende and Ihiagwa) P adsorption capacities. Similar observations have been reported for Nigerian soils by other workers (Udo 1985, Agbede 1988 and Osodeke and Omueti 1995). The low P sorption capacities imply that only a small amount of P fertilizer is required for maize growth in the soils. The capacity to sorp P follows a decreasing order of Ikom > Ihiagwa > Bende.Soil properties such as exchangeable aluminium, clay content, pH and soil organic matter affect the capacities of soils to adsorb phosphorus. There was a significant correlation between exchangeable aluminium, clay content, pH and organic matter with soil adsorption capacity. The relationships indicated that as the clay content, exchangeable aluminium and soil pH increased the P adsorption capacities also increased but decreased as the organic matter and exchangeable calcium content increased. Similar observations have been reported by other workers (Hakim 2002 and Bubba et al 2003). The variation in adsorption capacity with soil properties followed a decreasing order of exchangeable aluminium > clay content > soil pH > organic matter > exchangeable calcium.

Maize dry matter yield.

Maize dry matter yield at various P rates is presented in Figure. 2. Dry matter yield in Ikom increased with increasing P rates. The highest yield occurred at 103 kg/ha corresponding to an equilibrium solution P concentration of 0.2ppm. Yield at 52 kg/ha corresponding to equilibrium solution P concentration of 0.14 ppm P did not significantly differ from that at 103 kg/ha and yield at 56 kg/ha corresponding to solution concentrations of 0.17 ppm. Yield at zero P rate was however significantly lower than yields at other P rates. It followed that optimum maize yield in Ikom soil could be achieved at a P rate of 52 kg/ha. This is high when compared with maximum rate of 40 kg/ha proposed for soils of Southeastern Nigeria (Enwezor 1990) and soils of savanna zones of Nigeria (Kogbe and Adediran 2003). The high P rates for Ikom soil agree with the observation that in soils with large buffer power, large P dressing is required to ensure suitable P concentration for crop growth (Le Mare and Leon 1989).

In Bende, maize dry matter yield increased

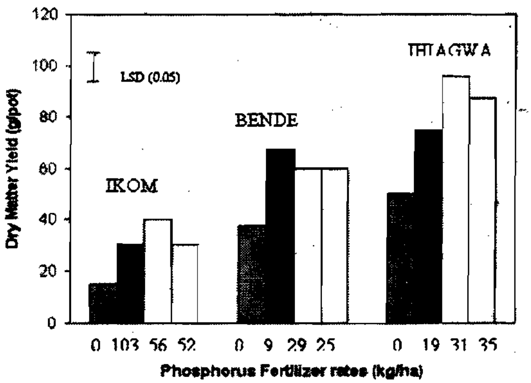

Fig. 2 Dry matter Yield at different P rates

with P application rate up to a particular point and decreased thereafter. The highest yield occurred at P application equivalent to 9 kg/ha and corresponding to equilibrium solution concentration of 0.2 ppm and decreased after this rate. Dry matter yield at 25 kg/ha corresponding to equilibrium solution P concentration of 0.34 ppm did not significantly differ from yield at 29 kg/ha, corresponding to equilibrium solution P concentration of 0.37 ppm and that at 9 kg/ha. Yield at thecontrol differed significantly with that at 9 kg/ha and 25 Different from that at 29 kg/ha. The decrease in yield beyond a particular P rate has been reported by other workers and attributed to low utilization pf nitrogen following large solution P concentration (Howard 2004) and nutrient imbalances (Kogbe and Adediran 2003). The optimum P rate for maize growth in the soil is 9 kg/ha. This agrees with reports of previous studies for Bende soil (Enwezor 1990).

Maize dry matter yield in Ihiagwa increased an increased P application rates up to 31 kg/ha corresponding to equilibrium solution P concentration of 0,34 ppm and decreased thereafter. Yield at zero P rate was significantly lower than that at all other P rates. Yield at 31 kg/ha did not differ significantly with that at 35 kg/ha corresponding to equilibrium solution P concentration of 0.36 ppm but was significantly higher than that at 19 kg/ha corresponding to solution P concentration of 0.2 ppm. It implies that optimum tmaize yield in the soil could be obtained at P rate equivalent to 31 kg/ha and corresponding to 0.34 ppm equilibrium solution P concentration. This falls within the range of 20 -40 kg/ha proposed for soils of Southeastern Nigeria (FPDD 1990). The high equilibrium solution P concentration of 0.34 ppm observed for the soil agrees with the findings of Wilcox and Paulo (1983) that soils with low adsorption capacity require a saturation of the adsorption sites and a high equilibrium solution P for maximum yield.

Generally, optimum maize yield for the soils occurred at equilibrium P concentration range that varied between 0.2 0.34 ppm. This is within the range of 0.01 to 0,4 ppm P proposed by Juo and Fox (1977) for near maximum growth of most crops and an equilibrium P concentration of 0.3 ppm for maximum growth of sweet maize in savanna soils of Northern Nigeria (Mokwunye 1978). The relative yield (Table 3) in the soils decreased in the order Ihiagwa > Bende > Ikom almost in a reverse order as the inherent fertility status of the soils. The low yield in Ikom and Bende relative to Ihiagwa could be attributed to the mechanical resistance to root penetration due to the high clay content of the soils. Esu (1987) reported that decreased soil porosity and resistance to root growth increased with increased soil clay content. It could also be due to aluminium toxicity. It has been reported that aluminium toxicity occur in soils with pH value less than 5.5 and increases in severity as the pH decreases below a value of 5.0 (Opara-Nadi 1988).

Phosphorus content of maize.

The P content of maize at different P fertilizer rates are presented in Table 3.

Tissue P in Ikom soil increased with increased application rate and solution P concentration. It was highest at P rate of 103 kg/ha. P content at 52 kg/ha and 56kg/ha did not differ significantly with that at 103 kg/ha. Tissue P at zero P rate was significantly lower than values at the other P rates. Tissue P varied as the dry matter yield showing that crop yield and

Table 3: Relative yield, maize P and Phosphorus use efficiency at various P rates.

Soil Type	P rates	Relative yield	Plant P	Plant PUE
Ikom	0	30	0.13b	-
	52	60	0.12ab	0.03
	56	80	0.26ab	0.05
	103	100	0.33a	0.03
	LSD (0.05)	-	0.04	-
Bende	0	56	0.21b	-
	9	100	0.38a	1.3
	25	89	0.34a	0.4
	29	74	0.26b	0.2
	LSD (0.05)	-	0.02	-
Ihiagwa	0	50	0.19c	-
	19	75	0.24b	0.53
	31	100	0.35a	0.65
	35	86	0.31a	0.43

Means followed by the same letters are not significantly different at 5% level using LSD.

solution P concentration determine P uptake in soils. The highest tissue P concentration in Bende occurred at a P rate of 9 kg/ha. This was however not significantly different from P at 25 kg/ha but higher than values at zero and 29 kg/ha. P at 29 kg/ha did not differ from at 0 kg/ha Indicating that P uptake at 29 kg/ha was greatly affected by antagonism resulting from nutrient imbalance due to high P application and soil solution P concentration (Booklin 1996). In Ihiagwa plant P followed the same trend as maize dry matter yield. Highest tissue P was at 31

Kg/ha. Tissue P at 35 kg/ha was not significantly different from that at 31 kg/ha but higher than that at zero and 19 kg/ha.

The phosphorus use efficiency (PUE) for the soils is shown in Table 3. The higher the rate of P application, the lower the PUE. Similar observation has been has been reported by Kogbe and Adediran (2003). This signifies that the efficiency of maize P utilization decreased as the P fertilizer rate increased. On the average every kilogram of P applied to maize produced 0.1 t/ha, 2.4 t/ha and 1.9 t/ha dry matter yield in Ikom, Bende and Ihiagwa respectively. The highest P use efficiency occurred at 52 kg/ha, 9 kg/ha and 31 kg/ha for Ikom, Bende and Ihiagwa respectively. Additional use of P fertilizer beyond this rate reduced the dry matter yield for every kilogram P by 19% in Bende and 13% in Ihiagwa but had no significant impact in Ikom probably due to lack of variation in yield at high P rates. Efficiency in P utilization was highest in Bende and could be explained by its low P adsorption capacity as well as the low tenacity with which adsorbed P was held, making it more readily available for maize uptake. The relatively high inherent soil nutrient status was also a factor. The low efficient P utilization in Ikom suggests the need for the inclusion of organic matter as management strategy for crop production. This would in addition to lowering its adsorption capacity also improve the structure for better plant root movement.

SUMMARY AND CONCLUSION

Generally the phosphorus adsorption capacities of the soils were low. The trend followed a decreasing order Ikom > Ihiagwa > Bende. The buffering power of these soils was related to adsorption capacity and was affected most by the soil properties especially exchangeable aluminium, clay content, exchangeable calcium, CEC, organic matter and pH. The influence of the soil properties follow a decreasing trend of exchangeable aluminium > clay content > pH > organic matter > exchangeable calcium > CEC.

All the soils were deficient in phosphorus and the amount of phosphorus fertilizer required for optimum yield of maize varied. These amounts were 52 kg/ha, 9 kg/ha and 31 kg/ha for Ikom, Bende and Ihiagwa soils respectively. Ikom with the highest aluminium and clay content had the poorest dry matter yield. The use of lime and organic matter would enhance maize performance.

The phosphorus content of the plant varied depending on the soil solution concentration and the plant yield. This signified that so long as P is available in soil solution, its efficient utilization will depend on the availability of other nutrients in addition to good rooting medium. The efficiency of phosphorus fertilizers decreased as the application rate increased. Bende soil showed the highest efficiency in P utilization. The use of sorption isotherm as a P management tool, offers an efficient approach for P fertilizer estimation for soils of Southeastern Nigeria

REFERENCES

Adepoju, A.Y (1985). Effects of phosphorus fertilization on maize yield on an entisol in the humid tropics. In Soil Fertility, Soil Tilth and Post Clearing Land Degradation in humid tropics. Proc. Inter. Soc. Sci. Commission IV and VI. pp 55-60.

Agbede, O.O (1988). Evaluation of phosphate adsorption capacity of some Nigerian rain forest soils. Proceedings of the 16th Annual Conf. of Soil Science Society of Nigeria .Minna, Niger state. Nov 27-30th 1988.

Allison, L.E. (1965). Organic carbon. In C.A.Black (Ed). Methods of soil analysis. Part2. American society of Agronomy. Wisconsin. P 999-1010

Booklin, J. (1996). Possible solutions to remedy the detrimental effects of soil acidity on tropical agriculture. Tropical Agriculture, vol 73, no.6, pp 302-310.

Bouyoucous, C.J. (1962). Hydrometer method improved for making particle size analysis of soils. Soil Sci Soc. Am. Proc. 26: 464-465.

Bubba, M.O, C.A. Arias and H. Brix (2003). Phosphorus adsorption maximum of sands for use as media in subsurface flow cultivated reed beds as measured by Langmuir isotherm. Water Research. 37. pp 3390-3400.

Esu, I.E (1987). Fertility status and management of some upland basement complex soils in the Nigerian tropical savanna region. Nig. Journ. Soil Science, vol.7.

Enwezor, W.O, A.C.Ohiri, E.E, Opuwaribo and E.J.Udo (1990). A review of fertilizer use on crops in Southeastern zone of Nigeria. In Literature review on soil fertility investigations in Nigeria (in five volumes). Produced by the Federal Ministry of Agriculture and Natural Resources. Lagos.

Ezenwa, M.I.S. (1987). Some physico-chemical characteristics of soils of basement complex and adjoining basaltic rocks of Northern Nigeria. Proceedings of the 15th annual conference of Soil Science Society of Nigeria.

FPDD, Fertilizer Procurement and Distribution Division (1990). A literature review of Soil and Fertilizer Use Research. In Literature review on soil fertility investigation in Nigeria. (eds. Enwezor et al), produced in five volumes by the Fertilizer Procurement and Distribution Division. Federal ministry of agriculture and Natural resources, Lagos, Nigeria

Fox, R.L and Kamprath, E.J (1970). Sorption isotherm for evaluating the phosphorus requirements of soils. Soil Sci. Soc. Amer. Proc.34:902- 907.Heald, W.R (1965). Calcium and magnesium. In C.A Black (ed).

Methods of soil analysis. Part 2. American society of Agronomy. Madison. P 1367-1378. Hakim, N (2002). Organic matter for increasing P fertilizer use efficiency of maize in Ultisols by 32 P technique. Symposium no. 59. Paper no. 229.17th World congress of

Soil Sience. Bangkok, Thailand 14-21 August. 2002.

Heald, W.R (1965). Calcium and magnesium. In C.A Black(ed). Methods of soil analysis. Part 2. American Society of Agromomy. Madison. P 1367-1378.

Howard, A.E. (2004). Agronomic thresholds for phosphorus in Alberta. A review. Alberta Agriculture, Food and Rural Development. Edmonton Alberta. Pp 52.

Isirimah, N.O (1987). An inventory of some chemical properties of selected soils of Rivers state of Nigeria. Proccedings of the 15th annual conference of Soil Science Society of Nigeria.

Jackson, M.L (1958). Soil chemical analysis. Englewood, California. N.J.

Juo, A.S.R and Fox, R.L (1977). Phosphorus sorption characteristics of somebench-mark soils of West Africa. Soil Sci. 124:370-376.

Jubrin, J.M, Chude, V.O, Horst, W.J and I.Y Amapu (2000). The response of Ten legumimous cover crops and maize to native and applied phosphate. Proc. 26th Anal. Conf. Soil Sci. Soc Nig. Ibadan, Oyo state Oct 30-Nov 3rd 2000.

Kogbe, J.O and Adediran, J.A. (2003). Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria. African Journal of Biotechnology. 2(10), pp345-349.

Le Mare, P.H and L.A. Leon(1989). The effects of lime and adsorption and desorption of phosphate on five Columbian soils. Soil Sci. 40 (1) 59-70.

Mokwunye, R. (1978). Phosphorus fertilizers in Nigeria savanna soils 1 Use of phosphorus sorption isotherm to estimate the phosphorus requirement of maize in Samaru. Samuru Res. Bull. 288.

Murphey, J and Riley J.P. (1962). A modified single method for the determination of phosphorus in natural waters. Anal. Chem. Acta. 27:31-36.

Nnadi, L.A and Haque, I. (1985). Estimating phosphorus requirement of native Ethiopian clover using phosphorus sorption isotherms. In Soil Fertility, Soil Tilth and Post Clearing Land Degradation in humid tropics. Proc. Inter. Conf. Soil Commission IV and VI. pp 82-90.

Opara-Nadi, O.A (1988). Liming and organic matter interactions in two Nigerian Ultisols. Effect of Soil pH, organic carbon and early growth of maize (Zea mays, L). Proceedings of the 16th annual conference of Soil Science Society of Nigeria

Osodeke, V.E and Omueti, J.A.I (1995). Phosphorus sorption characteristics of soils of the forest zone of southeastern Nigeria. Proc. 3rd African Soil Sci. Soc Conf. University of Ibadan.

Osodeke, V.E (1999). Determination of phosphorus requirement of rubber seedlings using sorption isotherms. Jour. Sust. Agric and Environ. Vol.1, June 1999.

Paul, L.W and Fred, N.M (1993). Sustaining soil productivity in intensive African agriculture. In overcoming soil constraints in crop production intropical Africa. Seminar proceedings. Accra, Ghana. 15-19 Nov 1993.

Sardi, K and Csatho, P (2002). Studies on phosphorus adsorption of different soil types and nutrient levels. 17th WCSS, 14-21 August 2002.Thailand.

Siemens, J, llG, K, Lang, F and Kaupeenjoham, M (2004). Adsorption controls mobilization of colloids and leaching of dissolved phosphorus. European Jour. Soil. Sci. 55(2) 253-260.

Udo,E.J (1985). Phosphorus status of major Nigerian soils. In soil fertility. Soil Tilth and Post Clearing Land Degradation in the Humid Tropics. Proc Inter. Soc Sci. Commission IV-VI.

Wilcox, E.G and Paulo, C, R.F. (1983). Establishing sorption isotherm to meet phosphorus requirement for tomato seedling growth. J. Plant Nutrition. 6 (30) 863-876.

Yuan, T.L (1959). Determination of exchangeable hydrogen in soils by titration method. Soil Sci. 88. 164-167.