Sorptivty Characteristics of Soil Phosphorus In Relation to Land Utilization Types

E. U. Onweremadu[1], M. C. Ofoh[2]

1. Department of Soil Science and Technology,
Federal University of Technology PMB 1526 Owerri, Nigeria.
E-mail: uzomaonweremadu@yahoo.com

2. Department of Crop Science and Technology,
Federal University of Technology, PMB 1526 Owerri, Nigeria

Abstract: Phosphorus (p) adsorption characteristics of 45 soil samples from 3 land utilization types (LUTs) were studied in soils of Owerri, Southeastern Nigeria during 2005/2006 cropping season. Some soil properties as well as selected P- adoption characteristics were studied in these LUTs, namely secondary forest (SF), cassava-based farm (CF) and continuously cultivated arable farm (CCF). The experiment was laid out in a randomized complete block design (RCBD) and farms were owner–managed. Results show differences in P- adsorption was greatly influenced by soil organic carbon (SOC), soil pH, exchangeable calcium, exchangeable aluminium and aluminium. Regression analysis shows that SOC and pH were the highest predictors of P-adsorption in soils of the study site, using the investigated LUTs. There is need for inclusion of more soil chemical, physical and mineralogical properties in predicting soil P- adsorption to enhance reliability of information. [Nature and Science. 2007;5(1):27-38].

Keywords: Adsorption, agriculture, land use, pedogenesis, phosphorus, tropical soil.

Introduction

The release of phosphorus (P) through natural processes is very scanty, whereas the sinks for P, especially at the floor of oceans are huge. In most agro ecosystem, P – losses outweigh gains, and unless augmented by man, P-cycles lose momentum. This is particularly true for tropical upland soils where deficiency of P is the most prevalent initial constraint to plant growth (von Uexkull, 1989). The uncertainties about P-chemistry in soils are due to its strong interaction with many organic and inorganic solid phases, continual uptake by plants and micro-organisms, continual return from organic decay and slow reaction rates (Isirimah et al., 2003). Although P-adsorption capacities of soil are influenced by Fe and Al oxides (Hakim, 2002), exchangeable calcium and magnesium, soil texture, porosity, pH, ionic strength and hydraulic conductivity (Bubha *et al.,* 2003), it has been reported that land utilization type influences P-adsorption capacity (Amapu *et al.,* 2000).

Man's land use activities affect global P-cycle. If p is applied to soil in excess of crop requirement, P will generally build up in the soil (Zhang *et al.,* 2005) and this increases the chances of P loss in the soil system (Sharpley *et al.,* 1999). Often, farmers practice land application of animal manure in order to meet crop nitrogen (N) needs and this results in over application of P as N/P ratio of most crops and pastures is 8:1 (USDA, 2001 while that of animal manures is 4:1 (Zhang et al., 2004). In paddy soils, Isirimah *et al.,* (2003) attributed high and continued phosphate availability to cycling of P between iron and aluminium forms.

Nnaji et al. (2002) observed variation in available phosphorus when soils of five land utilization types were evaluated. They reported that soils under maize –pepper intercrop, cassava-maize-pepper intercrop, sole cassava and cassava-maize intercrop were 68%, 27%, 14% and 11%, respectively higher than forest soil in available P. On highly weathered soils of Kenya, maize (Zea mays L.) yield doubled by applications of 50kg P ha^{-1} yr^{-1} as triple super phosphate (Bunemann *et al.,* 2004b) while crops had significant yield when it followed one –season Crotatlaria grahamiana planted fallow (Niang *et al.,* 2002; Smestad *et al.,* 2002). Application of $2tha^{-1}$ ash was optimum for soil pepper production and resulted to relatively high asoil P after the treatment (Odedina *et al.*, 2003). Intensive donkey drawn tillage on a steep slope led to a decline of available P within the tilled layer of 0-15 cm in upper and middle portions of the slope (Li *et al.,* 2004).

Phosphorus is a critical element in natural and agricultural ecosystems throughout the world (Onweremdu, 2007) as its limited availability is often the main constraint for plant growth in highly weathered soils of the tropics (Bunemann *et al.,* 2004a). Phosphorus deficiency problems are common in well –weathered oxisols and ultisols because of strong acidic reactions and abundance of Al and Fe ions (Saleque *et al.,* 2004), and the situation can be worsened with inappropriate P management (Saleque *et al.,* 1998) Rice removed about 2 to 3 kg P for 1 mg of grain produced (Timsina and Connor, 2001). All these show that P-availability and use by plants vary among plants. We hypothesize that P- availability and uptake relate to sorption characteristics of soil. Pased on the above, the major objective of this study was to investigate P- sorption characteristics as influenced by land utilization type (LUT).

Materials and methods

Study area: The research was carried out during the 2005/2006 cropping season at Owerri, Southeastern Nigeria. The study site is located on latitude $5^{0}43^{1}$ $14^{11}.623$ N and $7^{0}37^{1}34^{11}.490$ E., and with an elevation of 55 metres (handheld Global Positioning System – GPS) receiver (Garmin Ltd, Kansas, USA). The predominant parent material for underlying the area from which most soil formed is the Coastal Plain Sands (Benin formation) of the Miocene-Oligocene geological era. Soil are referred to as: "Acid sands", and are characteristically acidic, of low cation exchange capacity, low base saturation, low fertility status and suffer from multiple nutrient deficiencies (Oti, 2002). Earlier, soils were classified as Isohyperthemic Arenic Kandiudult (Onweremadu, 2006). The area has a humid tropical climate (Igwe and Stahr, 2004), with two distinct seasons, namely wet and dry seasons. Rainfall distribution is bimodal with peaks during the months of July and September. Temperatures are high and change only slightly during the year. Vegetation is described as rainforest and has multiple plant species that shade their green leaves at different times, making the forests "evergreen". However, the density of the rainforest has drastically reduced due to anthropogenic activities. Subsistence farming is a prevalent socio-economic activity in the area.

Experimental design: The study identified 15 plots of farmland located within the same area and at close proximity. These plots have been consistently under cultivation for 15 years and under one of the following land utilization types (LUTs): secondary forest (SF), cassava- based arable farm (CF) and continuously cultivated arable farm (CCF). Adequate care was taken to ensure the fields selected for a particular LUT have been subjected to similar cultural practices, such as uniform tillage system and application of manures over years. Farms were owner –managed and farmers belong to the same social setting and great uniformity was found in their farming practices. The experiment was managed by farmers except for researchers' technical input and collection of data. The experiment was a randomized complete block design (RCBD) with three LUTs as treatments. Five farmers' plots were used as replicates for each LUT. Each plot measured 400 m^2 (20 x 20 m). All data were taken from the inner 10 x 10 m^2 of each plot.

Soil Sampling: Fifteen soil samples were collected form each LUT at 0-20, 20-40 and 40-60 cm depths. A total of 45 soil samples were used for the study. In each treatment were 5 replicates and soil samples were collected at 3 depths. These soil samples were air-dried, and sieved using 2 –mm sieve in readiness for laboratory analysis.

Laboratory analysis: Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Soil pH was measured in 1:2.5 soil /liquid ratio in 0.1 N KCl (Hendershot *et al.,* 1993). Soil organic carbon (SOC) was estimated by combustion at 840^0C (Wang and Anderson, 1998). Exchangeable calcium and aluminium were measured using inductively coupled plasma atomic emission spectrometer (ICP – AES). Cation exchange capacity (CEC) was determined by percolating 2.5 g soil with 100 ml of I M ammonium chloride for about 4 hours. Before percolating soil samples, samples were soaked with extraction solution overnight. Aluminium saturation (Alsat) was computed as exchangeable aluminium (Al) divided by CEC multiplied by 100 percent.

Adsorption Isotherms: Phosphorus adsorption isotherms were determined according to the procedure of Graetz and Nair (2000). A gram of soil sample was equilibrated with 25 mL of varying concentrations of P in 0.01 M $CaCl_2$ solution in 50-ml centrifuge tubes. The concentrations of the solutions were 0.0, 0.5, 1.0, 5.0, 10.0, 15.0 and 20.0 mg P L^{-1}. The tubes were shaken for 24 hours on an end –to- end shaker at 150 oscillations per 60 seconds. The samples were then centrifuged for 10 minutes at 5211 x g and the supernatant decanted. The P in solution was then quantified calorimetrically using the ascorbic acid method (Kuo, 1996). The amount of P adsorbed was determined by the difference between initial and final amounts of P in solution. Duplicate analyses were conducted on all soil samples. Phosphorus adsorption isotherms were estimated with the linearized form of the Langmuir equation:

$$\frac{C}{S} = \frac{1}{KSmax} + \frac{C}{Smax} \quad \ldots \text{I.}$$

Where S = total of amount of P retained

C = Concentration of P after 24-hr equilibrium

Smax = P – sorption maximum

The Smax was calculated by regressing C/S versus C, where C is the equilibrium solution P concentration and S is adsorbed P. The reciprocal of the slope 'of mean regression is Smax (Zhang *et al.,* 2005).

Computations: The following calculations were made:

1. The amount of P remaining in solution was taken as equilibrium concentration and the difference between the initial concentration and equilibrium concentration was taken as adsorbed P.
2. The adsorption isotherm versus equilibrium concentration was plotted for each soil being investigated to obtain a straight line with slope of 1/b and intercept of 1/kb
3. The following form of Langmuir equation: C/C x1m = 1/kb+ c/b) was used to obtain adsorption capacities and constants related to bonding energy.

Where C= P concentration in equilibrium solution

x/m = P adsorbed by soil

b = adsorption maximum

k = constant related to bonding energy of soil for P (affinity constant)

Statistics: Correlation and regression analyse were performed to relate some soil properties and P- sorption characteristics using PC SAS version 8.2 (SAS Institute 2001).

Results

The properties of soils under LUTs are given in Table 2. Soils were generally sandy irrespective of LUT but SOC values were highest in soils of SF although values decreased with depth in all LUTs. Soil were strongly to moderately acidic and least pH value was recorded at 20-40 cm depth under SF. The same layer had the highest value of Alsat (aluminium saturation) and least exchangeable calcium.

Phosphorus adsorption characteristics are shown on Table 3, indicating variabilities in the P-adsorption characterstics of studied soil. Soils under SF had steeper slopes. Values of Langmuir adsorption constants, equilibrium P and buffering capacity for soils of the LUTs are indicated on Table 4. The standard P requirements (P adsorbed at a standard concentration of 0.2 mg P) were low for the LUTs and results were consistent with the findings of Osodeoke (1999). Also, the adsorption maxima at low equilibrium solution P concentrations are generally low with values obtained in Western Nigerian soils (Osodeoke, 1999) but moderate with results of P-studies conducted by Kwari and Batey, (1991) in

Northcastern soils of Nigeria. Adsorption maxima decreased in this order: CCF, CF and SF and the same trend was followed by k-values (affinity constant values). But buffering capacity value was highest in CCF and least in SF.

Simple correlation result between P-adsorption characteristics and some soil properties are shown (Table 5). Soil clay and Alsat influenced adsorption maxima of P in soils under SF. Similar findings were made by Zhang et al. (2005) when clay was correlated with Smax (r=0.7.9) while Borling et al. (2001) found significant relationships between oxides of aluminium and Smax. Under CF, soil pH and exchangeable calcium had highest relationship with P-adsorption capacity while in all LUTs, there were negative relationship between P adsorption capacity and SOC. Unlike results of other researchers (Dodor and Oya, 2006; Zhang *et al.,* 2005) soil pH had significant ($P < 0.01$) relationship with P-adsorption. Exchangeable Ca was significantly and negatively correlated ($P<0.05$) with P-adsorption and this contrasts the results of other researchers (Sims *et al.,* 2002). Higher correlation values were established between exchangeable Ca and P – adsorption in CCF. Phosphorus predictive capacities of individual soil properties are presented on Table 6. The P- predictive ability of soil pH decreased in the order of CCF CF and SF while SOC had higher prediction of P- adsorption in CCF and SF when compared with CF. Least coefficient of alienation ($1-R^2$- 0.23 was found in the relationship between exchangeable Ca and P-adsorption

Table 1 Cultural practices associated with each land utilization type (LUT) in the study site

LUT	Cultural Practices
SF	Land clearing by slash and burn, natural fertility regeneration
CF	Land clearing by slash and burn, soil amended with animal manures and inorganic fertilizers. Cassava + maize + okra + pepper intercropping
CCF	Land clearing included slashing, stumping and packing debris in heaps more applications of animal manure, compost, farm yard manure and inorganic fertilizers multiple cropping including groundnut (Arachis hypogea)

SF = Secondary forest, CF = Cassava =based farm, CCF = continuously cultivated arable farm

Table 2 Selected properties of the studies soil (mean values)

LUT	Depth (cm)	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})	SOC (g kg^{-1})	Ca (cmol kg^{-1})	Al (cmolkg^{-1})	CEC (cmol kg^{-1})	Alsat (g kg^{-1})	pH (KCl)
Secondary forest	0-20	330	70	600	14.0	6.6	4.0	12.2	42	4.4
(SF)	20-40	350	60	590	6.0	5.1	4.3	8.2	50	3.8
	40-60	360	60	580	2.0	15.6	3.9	11.6	38	4.5
Cassava based	0-20	300	50	650	18.0	16.8	4.6	11.0	44	4.4
Arable farm	20-40	360	70	570	6.0	11.2	4.9	9.2	46	4.6
(CF)	40-60	305	70	625	1.0	18.6	3.7	10.6	38	4.6
Continuously	0-20	290	40	670	14.8	15.3	5.0	10.8	43	4.8
Cultivated arable	20-40	340	60	600	3.0	11.0	5.2	9.6	44	4.6
Farm (CCF)	40-60	400	80	520	2.6	17.9	3.6	10.6	39	4.8

LUT – land utilization type SOC = soil organic carbon, Alsat = aluminium saturation, Ca = calcium, Al = aluminium CEC = cation exchange capacity.

Table 3. Phosphorus adsorption properties of studied soil (mean values)

LUT	Depth (cm)	EPC (mg Pg^{-1})	Ad. P (mg P ml^{-1})	EPC/Ad.P
SF	0-20	0.02	10.01	0.002
	20-40	0.73	9.25	0.079
	40-60	0.60	9.55	0.063
CF	0-20	0.30	17.66	0.017
	20-40	2.71	21.25	0.127
	40-60	0.70	16.65	0.042
CCF	0-20	1.21	30.25	0.040
	20-40	2.72	33.40	0.081
	40-60	0.90	41.26	0.022

LUT = land utilization type SF = Secondary forest, CF = Cassava = based arable farm
CCF = Continuously cultivated arable farm, EPC= equilibrium P concentration
Ad.P = adsorbed P .

Table 4. Values of Langmuir adsorption constants (adsorption maximum affinity constant), equilibrium P and buffering capacity (mean values)

LUT	ECR (mg P g^{-1})	AM (b)	AC (k)	0.2 mg P	BC (mg P g^{-1})
SF	0.0 -0.8	20.0	1.0	4.1	28.0
	0.8-6.0	76.0	0.1	-	-
CF	0.0 -0.8	26.0	1.2	2.9	26.1
	0.8 -5.8	72.0	0.3	-	-
CCF	0.0 -0.8	28.8	1.8	2.2	24.3
	0.8 -5.2	78.4	0.4	-	-

LUT = land utilization type, SF = Secondary forest, CF = cassava-based arable farm

CCF = continuously cultivated arable farm, ECR = equilibrium concentration range, AM = adsorption maximum, AC = affinity constant, BC = buffering capacity.

Table 5. Simple correlation (r) between Langmuir adsorption constants, 0.2 mg P and selected soil characteristics (n = 45).

LUT	Soil properties	b	k	0.2 mg P
SF	pH (KCl)	0.62**	0.68*	0.66*
	SOC (g kg^{-1})	- 0.60**	0.58*	0.65*
	Ca (cmol kg^{-1})	- 0.60 *	0.38 NS	0.51*
	Alsat (g kg^{-1})	0.79**	0.88**	0.90**
	Clay (g kg^{-1})	0.88*	0.91**	0.92**
CF	pH (KCl)	0.88**	0.81*	0.68*
	SOC (g kg^{-1})	- 0.74*	0.63*	0.52*
	Ca (cmol kg^{-1})	- 0.88**	0.56**	0.53*
	Alsat (g kg^{-1})	0.62**	0.77*	0.80**
	Clay (g kg^{-1})	0.72**	0.82**	-0.86**
CCF	pH (KCl)	0.96 **	0.83**	0.51*
	SOC (g kg^{-1})	- 0.98**	0.43 NS	0.25 NS
	Ca (cmol kg^{-1})	- 0.82**	0.48*	0.34 NS
	Alsat (g kg^{-1})	0.41 NS	0.87**	0.88**
	Clay (g kg^{-1})	0.37*	0.96**	- 0.91**

LUT = land utilization types, SF = Secondary forest, CF = cassava-based arable farm,

CCF = continuously cultivated arable farm SOC = Soil organic carbon, Ca = calcium, Alsat = aluminium saturation, b = adsorption maxima, k = affinity constant, ** significant at P = 0.01, * significant at P = 0.05, NS not significant.

Table 6. Pedotransfer functions relating adsorption of P (Y) to some soil properties (n=45)

LUT	Independent variable	Regression equation	R^2	$1-R^2$
SF	pH (KCl)	Y = 17.6 – 41.63 pH	0.62	0.38
	SOC (g kg $^{-1}$)	Y = 38.6 – 6.11 OC	0.74	0.26
	Ca (cmol kg $^{-1}$)	Y = 31.2 – 1.25 Ca	0.59	0.41
	Alsat (g kg $^{-1}$)	Y = 26.8 + 0.98 Alsat	0.62	0.38
	Clay (g kg $^{-1}$)	Y = 33.2 + 1.16 Clay	0.46	0.54
	0.2 mg P	Y = 28 . 6 + 0.22 mg P	0.55	0.45
CF	pH (KCl)	Y = 22.1 – 46. 18 pH	0.77	0.23
	SOC (g kg $^{-1}$)	Y = 31.2 – 0.92 OC	0.55	0.45
	Ca (cmol kg $^{-1}$)	Y = 29.1 – 0.06 Ca	0.77	0.23
	Alsat (g kg $^{-1}$)	Y = 30.3 + 0.07 Alsat	0.38	0.62
	Clay (g kg $^{-1}$)	Y = 25.6 + 0.27 clay	0.52	0.48
	0.2 mg P	Y = 30.3 + 0.02 mg P	0.59	9.41
CCF	pH (KCl)	Y = 19.0 – 52. 12 pH	0.92	0.08
	SOC (g kg $^{-1}$)	Y = 29.8 – 0.13 OC	0.96	0.04
	Ca (cmol kg $^{-1}$)	Y = 23.2 – 0.09 Ca	0.67	0.33
	Alsat (g kg $^{-1}$)	Y = 35.1 + 1.11 Alsat	0.17	0.83
	Clay (g kg $^{-1}$)	Y = 26.3 + 0.09 Clay	0.59	0.41
	0.2 mg P	Y = 29.2 + 0.12	0.61	0.39

Discussion

Soil were generally sandy in all the LUTs, indicating similarity in parent material source. Slight variations in soil texture and other properties could be attributed to land use history and differential impact of climatic factors on soils. Onweremadu et al. (2007a) noted slight temporal textural differences in arable soils resulting from continuous cultivation. Exchangeable Ca was high in surface layers of soils under CCF and CF while it increased with depth in soil of SF, suggesting leaching of exchangeable Ca to deeper soil layers. This is further confirmed by high Alsat (50%) and strong acidity (pH_{KCl} = 3.8) Values of P-adsorption attributes varied indicating ability of soils under different LUTs to adsorb P. Steeper slopes in soil of SF is suggesting higher buffering capacity of soils when compared with soils of other LUTs. However, relatively lower buffering capacities of soil under CF and CCF could be attributed to varying additions of inorganic fertilizers while higher values of CEC in soils under SF is suggestive of higher buffering capacities. Soils with largest cation exchange capacities offer greatest resistance to change in pH and are most strongly buffered (Foth, 1984).

The standard P requirement values, that is, P adsorbed at a standard concentration .of 0.2 mg kg^{-1} varied among LUTs and were low in the study areas. Least values were obtained in CCF, possibly due to multiple cropping and continuous cultivation of soils. There exists two distinct linear potions as calculated form the regression equations implying that these soil had two adsorption maxima (b) and affinity constants (k). It is argued that P-adsorption capacity as suggested by the population of sites in the low equilibrium P (first linear portion) is more important than that of the second linear portion as they represent P- levels for crop production when fertilized (Udo 1981). High values of P-adsorption maxima in CCF soils at high ECR could be due to more population of adsorption sites. High values of k (affinity constants), implying greater bonding energy in the first linear portions show that the tenacity of P-adsorption is higher at low P equilibrium concentration, and these attributes varied with LUT.

In all LUTs, P- adsorption characteristics were influenced by some soil properties, although at varying levels. Soil properties that correlated with P- adsorption were pH, SOC Alsat, exchangeable Ca and clay. Similar relationships were recorded by Burt et al. (2002). Studied soils are highly weathered and the presence of organic matter reduce P- sorption capacity (Gillman et al., 1989) due to direct result of competition for sorption sites between phosphate and organic ligands (Hakim, 2002). He also reported that the same competition exists between Al and Ca. it is also possible that organic matter reduces positive charge on variable charge surfaces by lowering pH, and this decreases the attraction of P to the soil surface. This effect was more in soils under SF than in other soils, indicating that anthropogenic activities do alter soil properties.

Soil organic carbon and pH had high values of coefficient of determination, having r^2 = 0.96 and r^2 = 0.92, respectively, indicating that these predictors can be used to predict P-sorption and P – availability with high degree of confidence in soils of these LUTs.

Conclusion

Sound knowledge about P-sorption properties in soils under different LUTs is necessary in sustained use of soil for crop production. Results of this study revealed differences in P- adsorption due to land use and identified soil pH and SOC as main predictors of P activity in the study areas. There is need for more intensive sampling and multiple regression of physical, chemical and mineralogical properties of soils for more reliable information on soil properties on prediction of P.

Correspondence to:
Dr. Emmanuel U. Onweremadu
Department of Soil Science and Technology
Federal University of Technology
PMB 1526 Owerri – Nigeria
E-mail:uzomaonweremadu@yahoo.com

Received: March 28, 2007

References

1. Amapu, I.Y., Chude, V.O., Singl , U., Jubrin, J.M. and Adam, S. (2000). Testing a dynamic phosphorus model in the sub-humid Nigeria savannah agro-ecology. Proceedings of the 26th Annual conference of soil science society of Nigeria, Ibadan, Oyo State Nigeria, Oct 30-Nov 3 2000. pp 270-278
2. Borling K., Ottabong, E. and Barberis, E. (2001). Phosphorus sorption in relation to soil properties in some cultivated Swedish Soils. Nutr. Cycling Agroecosyst., 59:39-46.
3. Bubba, M.O. Arias C.A and Porix, H. (2003). Phosphorus adsorption maximum of sands for use as media in subsurface flow cultivated reed beds as measured by the Langmuir adsorption isotherms. Water Res., 3390-3400.
4. Bunemann, E.K., Steinebruner, F., Smithson, P.C., Frossard, E. and Oberson, A. (2004a). Phosphorus dynamics in a highly weathered soil as revealed by isotopic labelling techniques. Soil Sci. Soc. Am. J., 68:1645-1655.
5. Bunemann, E. K Boss D.A. Smithson, P.C., Frossand, E. (2004b) Microbial community composition and substrate use in a highly weathered soil as affected by crop rotation and P – fertilization. Soil Biol. Biochem., 36:889-901.
6. Burt, R., Mays, M.D. Benham, E.C. and Wilson, M.A. (2002). Phosphorus characterization and correlation with properties of selected bench mark soil of the United States. Commun. Soil Sci. Plant Anal., 33:117-141.
7. Dodor, D. E. and Oya, K. (2000) Phosphorus sorption characteristics of major soils in Okinawa, Japan. Commun. Soil Sci Plant Anal., 31: 277-288
8. Foth. H.D. (1984). Fundamentals of Soil Science. 7th edition. John Wiley and Sons, New York.
9. Gee, G. W. and Or, D. (2002). Particle size analysis. In: Dane, J.H. and Topp, G.C. (Eds). Methods of soil analysis. Part 4 Physical methods. Soil Sci. Soc. Am Book Series 5. ASA and SSSA, Madison, W1 pp. 255-293
10. Gillman, G.P, Shamshuddin, J, and Bell L.C. (1989). Soil chemical parameters and organic matter in soil management. In: Pushparajah, E. (Ed). Soil management and smallholder development in the pacific Islands. Proceedings of a workshop organized by the International Board for Soil Research and Management (IBSRAM), Bankgkok, Thailand pp 141-155
11. Hakim, N. (2002). Organic matter for increasing P fertilizer use efficiency of maize ultisol by using ^{32}P technique. Symposium No 59, paper No 229 World congress on soil Science Bankgkok, Thailand, 14 -21 August, 2002.
12. Hendershot, W. H. , Lalande, H. and Duquette, M. (1993). Soil reaction and exchangeable acidity. In: Carter, M. R. (Ed). Soil Sampling and Method of analysis. Can. Soc. Soil Sci., Lewis Publishers London, Pp 141-145.

13. Igwe, C. A. and Stahr, K. (2004). Waterstable aggregates of flooded Inceptisols from southeastern Nigeria in relation to mineralogy and chemical properties. Austr. J. Soil Res., 42:171-179.
14. Kwari, J.D. and Batey T. (1991) Effect of heating on phosphate sorption and availability some Northeastern Nigeria soils. Soil Sci., 42 (3): 381-388.
15. Isirimah, N.O. Dickson, A.A. and Igwe, C.A. (2003). Introductory soil chemistry and biology for agriculture and biotechnology, OSIA Int'L Publishers Ltd., Port Harcourt.
16. Li, Y., Tian, G., Lindstrom, M. J. and Bork, H.R. (2004). Variation of surface soil quality parameters by intensive donkey drawn tillage on steep slope. Soil Sci Soc Am. J., 68: 907-913
17. Niang, A.I., Amadalo, B.A., de Wolf, J. and Gathumbi, D.M. (2002). Specials screening for short-term planted fallows in the highlands of Western Kenya. Agrofor. Syst, 56:145-154.
18. Nnaji, G.U., Asadu, C.L.A and Mbagwu, J.S.C. (2002). Evaluation of physico-chemical properties of soil under selected agricultural land utilization types. Agro-Sci., 3(1): 27 -33.
19. Odedina, S.A., Odedina, J.N., Ayeni, S.O., Arowojolu, S.A., Adegeye S.D. and Ojeniyi, S.O.(2003). Effect of types of ash on soil fertility nutrient availability and yield of tomato and pepper. Niger J. Soil Sci., 13., 61-67.
20. Onweremadu, E.U. (2007). Predicting phosphorus sorption characteristics in highly weathered soil of South –Eastern Nigeria. Res. J. Environ. Sci., Academic Journals, USA (In Press).
21. Onweremadu, E.U. Eshett, E.T. and Osuji, G.E., (2007a). Temporal variability of selected heavy metals in automobile soil. Int. J. Environ. Sci Tech., 4 (1) :35-41.
22. Onweremadu, E.U., C.C. Opara, U. Nkwopara, C.I. Duruigbo and I. I. Ibeawuchi (2004b). Yield response of a cowpea variety on ground seashells on Isohyperthemic Arenic Kandiudult of Owerr, Southeastern Nigeria. Int. J. Soil Sci, 1:251-257.
23. Osodeke, V.E. (1999). Determination of phosphorus requirement of rubber seedlings using sorption isotherms. J. Sust. Agric and Environ., 1:49-54.
24. Oti, N. N. (2002). Discriminate functions for classifying erosion degraded lands at Otamiri, Southeastern Nigeria. Agro-Sci., 3 (1) : 34-40
25. Saleque, M.A. Abedin M.J., Panaullah, G.M. and Bhuyian, N.I. (1998). Yield and phosphorus efficiency of some lowland rice varieties at different levels of soil available phosphorus. Commun. Soil Sci Plant Anal., 29: 2905-2916.
26. Saleque, M.A., Naher, U.A,. Islan, A., Pathan, A. B. M.U., Hossain, A.T.M.S., and Meisner, C.A (2004). Inorganic and organic phosphorus fertilizer effects on the phosphorus fractionation in wetland rice soils. Soil Sci. Soc. Am. J., 68: 1635 – 1644.
27. SAS Institute (2001). SAS user's guide: Statistics, Ver. 8.2, Cary, N.C.
28. Sharpley, A.N., Daniel, T., Sims, J. T., Lemunyon, J., Stevens, R. and Parry, R. (1999). agricultural phosphorus and eutrophication USDA Misc Publ ARS -149. US Gov Print Office, Washington DC.

29. Sims, J.T. , Maguire, R.O. Leytem, A.B., Gartely, K.L., and Pautler, M.C. (2002) Evaluation of Mehlich – 3 as an agri-environmental soil phosphorus test for the Mid-Atlantic united states of America. Soil Sci Soc. Am. J., 66: 2016 -2032.
30. Smestad, B.T., Tiessen, H., and Buresh, R.J. (2002). Short fallows of *Tithonia diversifolia* and crotalaria grahamiana for soil fertility improvement in Western Kenya. Agrofor. Syst., 55: 181-194.
31. Timsina, J. and Connor, D.J. (2001). Productivity and management of rice-wheat cropping systems: Issues and challenges. Field crop Res. 69:93-132.
32. Udo, E. J. (1981). Phosphorus forms, adsorption and adsorption in selected Nigeria soils. Niger. J. Soil Sci., 2:51-66.
33. USDA (united States Department of Agriculture) (2001). Comprehensive nutrient management planning technical guidance. USDA – NRCS, Washington, DC.
34. von Uexkull, H.R. (1989). Nutrient Cycling. In: Pushparajah, E. (ed). Soil Management and smallholder development in the Pacific Islands proceedings of the workshop organized by The International Board for Soil Research and management, Bangkok Thailand , Pp 121-132
35. Wang, D. and Anderson, D.W. (1998). Direct measurement of organic carbon content in soil by the Leco CR-12 carbon analyzer. Commun Soil Sci Plant Anal., 29:15-21.
36. Zhang, 4., Jognson, G., and Fram, M. (2004). Managing phosphorus from animal manure. Oklahoma Cooperative Extension fact sheet No F-2249. Oklahoma State University, Stillwater, Ok.
37. Zhang, H., Schroder, J.L. Fuhrman, J.K., Basta, N.T., Storm, D.E and Patron, M.E. (2005). Path and multiple regression analyses of phosphorus sorption capacity. Soil Sci. Soc Am . J., 69:96-106.