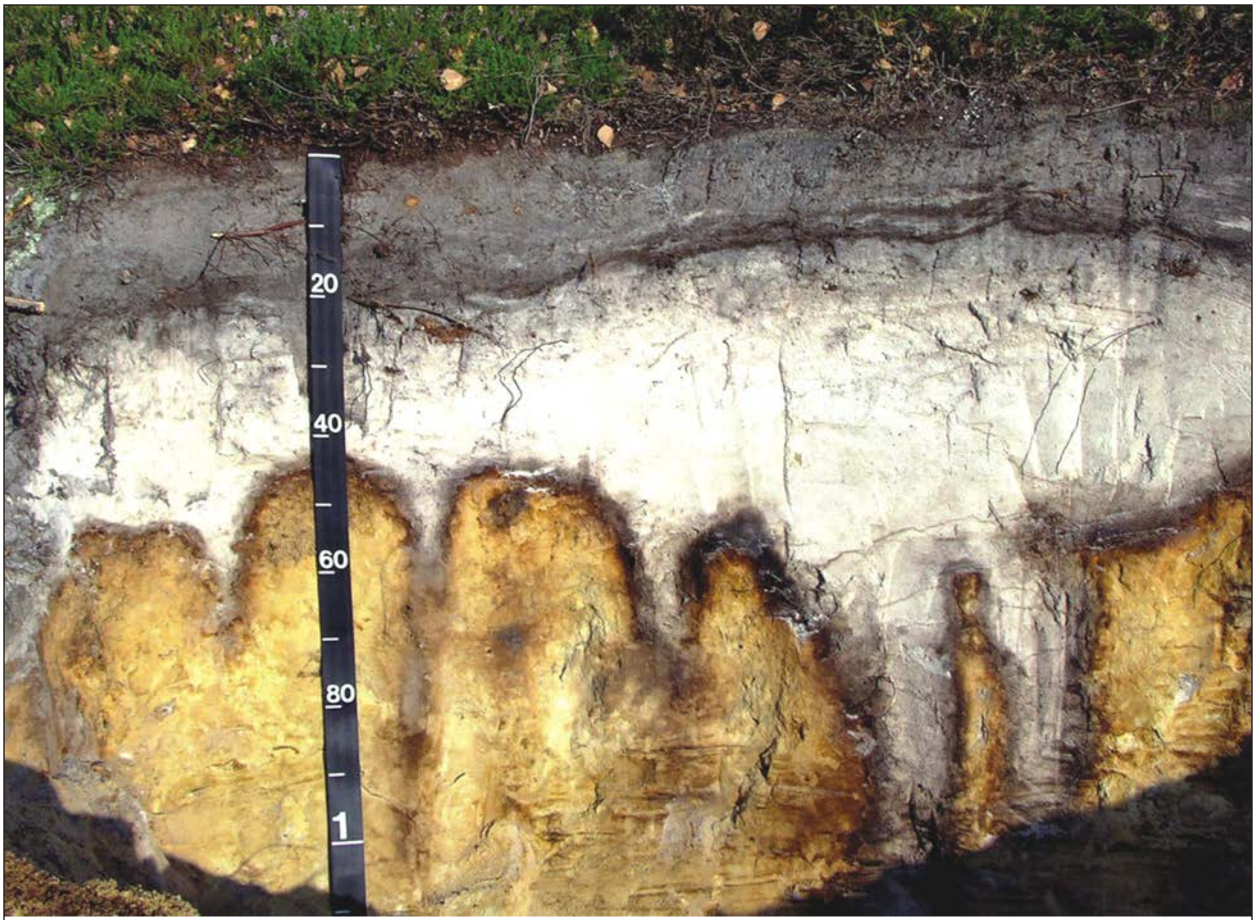

International Journal of
Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 2 (3): 182-189, 2007
ISSN 1816-4978

Lithosequential Variability in Phosphorus (P) Forms in the Humid Tropics

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Abstract: A field study was conducted in the months of March, April and May 2006 to investigate variability in P-forms in soils derived from 4 different parent materials, namely coastal plain sands, shale, basement complex rocks and a mixture of cretaceous sandstones and shales. A free survey approach was used in setting soil profile pits. Soil samples were prepared for Laboratory analysis. Variability was established in soil groups using Coefficient of Variation (CV) while relationship existing between P-form and soil properties was ascertained by correlation analysis. Results indicate that occluded P was the most abundant P form and this is environmentally unhealthy. Iron-P and aluminum-P predominated over calcium P, Most P-forms showed slight to moderate variation ($CV \leq 50\%$). Clay content had significant correlation ($p<0.05$) with P-forms hence can be used as a reliable predictor of variability of P-forms.

Key words: Chemistry of P, humid climate, lithology, tropical soils, variability

INTRODUCTION

Detailed information on the amounts and mobility of P in soils for effective farm management (Toor *et al*., 2003). Studies have suggested that P-losses vary from one event to another depending on amount, intensity and duration is vital of rainfall (Edwards and Daniel, 1993; Sharpley, 1997), indicating climate type influences P-form. Giesler *et al.* (2005) reported variation in Fe-P and Al-P in humus soils due to differences in sorption characteristics and this affects the availability of P for plants and micro-organisms (Giesler *et al*., 2004) and transfer of P from terrestrial to aquatic ecosystems (Lyons *et al*., 1998). Again, the type of parent material influences the form and availability of soil phosphorus, hence perform once and retention in Andisoils differ from that arising from humus or organically formed soils (Giesler *et al*., 2005). The chemistry of phosphorus forms in soils and consequently availability influences rate of uptake (Isirimah *et al*., 2003). Mineral forms, such as variscite, strengite and isomorphous series between the two have solubilities in the range of octocalcuim phosphate and apatite in alkaline soils.

There is a lack of information on various forms of P as related to parent materials in the humid tropical climate of Nigeria. Attempts to identify phosphate, phosphine and organophosphorus compounds have been unsuccessful (Isirimah *et al*., 2003). But soil phosphorus is a major limiting factor in the productivity of soils of the densely populated study area. There are many uncertainties surrounding phosphate chemistry in soils due to the element's strong interaction with many inorganic and organic solid phases, continual uptake by plants and microbes, continual return from organic decay and slow reaction rates. The objective of this study was to determine the concentrations and forms of phosphorus in soils derived from different lithologies in southeastern Nigeria. Concentrations of these P-forms will be related to some physicochemical properties of soils of the study area.

MATERIALS AND METHODS

Study Area

Southeastern Nigeria lies between latitudes 4°15^{1} and 7°00^{1}N and longitudes 5°50^{1} and 9°30^{1} E (Onweremadu, 2006). The major geological materials from which soils were derived include basement complex rocks, coastal plain sands, shale, upper coal measures, lower coal measures, cretaceous sandstones and falsebedded sandstones (Orajaka, 1975). Annual bimodal rainfall is over 1800 mm, with a very high intensity and occurs from April to November (Obi and Salako, 1995). Temperatures are high and uniform throughout the year with little variation. Tropical rainforest is the dominant vegetation, though with remarkable diversity caused by anthropogenic activities, especially farming and deforestation. Farming is a major socio economic activity and soil fertility regeneration is by bush fallow.

Field Studies

Field surveys were conducted before the on-set of rains in 2006 at the 4 selected locations. A free survey method was used and guided by the geological map of the study area (Onweremadu, 2006), 4 soil profile pits were dug in 4 locations, representing 4 parent materials. The 4 locations were Owerrinta (Coastal Plain Sands), Bende (Shale), Ogoja (Cretaceous sandstones and shales) and Obubra (Basement Complex Rocks). A total of 30 soil samples were collected from observed 30 pedogenetic horizons and this varied among soil groups. Eight soil samples were sampled from soil profile pit derived from Coastal plain sands, while 9, 7 and 6 soil samples were obtained from soils over Shale, Basement Complex Rocks and Cretaceous sandstones/shales, respectively. Soil samples were collected from bottommost horizon upwards based on horizon differentiation. These profile pits were described according to FAO (1998) guidelines and soils were later classified using USDA Soil Taxonomy (Soil Survey Staff, 2003). A total of 30 soil samples were collected, air dried, crushed and sieved using 2 mm sieve in readiness for Laboratory determinations.

Laboratory Analyses

Particle size distribution was estimated by hydrometer method (Gee and Or, 2002). Soil pH was determined electrometrically in water using a soil-water ratio of 1:2.5 (Hendershot *et al*., 1993). Soil organic carbon was measured by combustion at 840°C while total soil carbon was estimated at 1140°C using a Leco CR-12 C analyzer (Leco Corp, St. Joseph, MI) (Wang and Anderson, 1998). Inorganic carbon was calculated as a difference between total soil carbon and soil organic carbon.

The P-fractions were determined colourimetrically (ammonium-molybdate stannous chloride) as outlined by Tiessen and Moir (1993). Suspensions of extracts were filtered using Whatmen No. 42 filter paper and absorbance readings were recorded at 880 nm wavelength for different P-fractions using UV/VIS. Unicam Spectrocolourimeter. The inactive P(occluded P) was computed as the difference between total P and the active fractions, namely Al-P, Ca-P and Fe-P.

Statistics

Variability in soil P-forms based on parent materials was estimated using Coefficient of Variation (CV) statistic in SPSS version 10 (SPSS Inc., 1999) and degree of variability was ranked according to the procedure of Aweto (1982). Relationship existing between P-forms and selected soil properties was done by subjecting soil data to correlation analysis.

RESULTS

Soil Properties

Sand-sized soil particles dominated the texture of the study site while soils were strongly to moderately acidic (Table 1). Soil Organic Carbon (SOC) dominated the total soil carbon content of

Table 1: Some soil properties of studied sites

Lithology	TSC (g kg^{-1})	SIC (g kg^{-1})	SOC (g kg^{-1})	pH	Sand (g kg^{-1})	Silt (g kg $^{-1}$)	Clay (g kg^{-1})	Depth (cm)
Coastal plain sands (Owerrinta)	20.2	4.2	16.0	4.4	860	30	110	0-12
	17.2	3.1	14.1	4.3	890	20	90	12-30
	11.3	2.2	9.1	4.5	840	40	120	30-60
	9.1	2.1	7.0	4.5	830	40	130	60-101
	7.2	2.0	5.2	4.6	810	50	140	101-130
	4.8	1.6	3.2	4.8	780	40	180	130-165
	2.3	1.0	1.3	4.8	775	44	181	165-220
	1.5	0.4	1.1	4.6	800	40	160	220-260
Shale (Bende)	31.2	4.6	26.6	4.5	690	50	260	0-10
	22.8	3.2	19.6	4.5	720	40	240	10-30
	17.2	3.0	14.2	4.6	675	60	265	30-62
	11.9	2.8	8.1	4.8	652	80	268	62-80
	10.8	2.6	8.2	4.8	610	100	290	80-100
	8.2	2.1	6.1	4.8	542	80	298	110-130
	5.5	1.4	4.4	4.9	590	90	320	130-170
	3.3	1.2	2.1	4.9	530	90	380	170-190
	1.8	0.6	1.2	4.8	500	80	420	190-225
Basement complex rocks (Ikom)	27.6	5.6	22.0	4.8	770	40	90	0-6
	21.2	4.2	17.0	4.6	900	40	60	6-11
	18.8	3.6	15.2	5.1	835	50	115	11-36
	17.1	3.0	14.1	5.2	830	40	130	36-50
	14.7	2.6	12.1	5.1	828	40	132	50-150
	5.8	2.6	5.2	5.2	825	40	135	150-170
Cretaceous sandstone/shale (Ogoja)	25.2	4.6	20.6	5.0	835	45	120	0-7
	18.2	3.1	15.1	5.1	840	30	130	7-55
	15.8	3.2	12.6	5.4	700	42	258	55-110
	11.3	2.2	9.1	5.4	680	50	270	110-152
	8.8	0.6	8.2	5.6	660	40	300	152-176
	3.4	0.2	3.2	5.5	664	40	296	176-220

SOC = Soil Organic Carbon; SIC = Soil Inorganic Carbon; TSC = Total Soil Carbon

soils (Table 1). Specifically, soils derived from Coastal Plain Sands and Basement Complex Rocks were the sandiest when compared with other soil groups while higher soil pH values were recorded in soils formed over Basement Complex Rocks and Cretaceous Sandstones/shale. Generally, clay content of soils increased with depth in all soil groups while soil carbon content decreased with depth. Highest values of soil organic carbon were found in soils derived from shale at Bende, Abia State, Nigeria.

Phosphorus Forms

Analytical results on P-forms from 4 soil groups studies are shown in Table 2. Generally Occluded P dominated other P-fractions in the study site irrespective of lithological origin. However, occluded P had high variation among the P-forms (CV = 52.5%) while Ca-P had the least value of CV = 2.6% in the study site. In soils developed over Coastal Plain Sands, Fe-P and Org-P forms were more abundant than others. While Org-P decreased with depth, Occ-P increased with depth with the highest value (108.6 mg kg^{-1}) recorded at 60-101 cm depth. Available P(Bray II extractable P) was highest at the epipedal horizons.

Shale-derived soils had highest value of Ca-P followed by soils developed over Basement Complex Rocks. Yet, the greatest occlusion among soil groups occurred in a mixture of shale-derived soils, followed by soils formed over cretaceous sandstones and shale-with mineral in activity of soil P shown in soils derived from Basement Complex Rocks at Ikom, Cross River State, Nigeria. Least values of Al-P on the surface layer were recorded in soils derived from a mixture of cretaceous sandstone and shale at Ogoja, Cross River State, Nigeria (Table 2).

The available P (Av-P) which has immense agronomic influence in the area had little variation (CV = 14.3%) in all studied soils. Generally, P was most available in soils formed over Basement Complex Rocks and least available in soils developed on Coastal Plain Sands.

Table 2: Phosphorus forms in studied soils

	Fe-P	Al-P	Ca-P	Org-P	Occ.P	Av-P	
Depth (cm)	---------------(mg kg^{-1})---------------						Total P
Soils from coastal plain sands (Owerrinta)							
0-12	68.1	2.1	9.8	70.1	40.2	21.0	235.3
12-30	60.2	45.2	2.2	59.3	40.1	8.2	215.2
30-60	30.1	2.9	4.0	44.1	99.2	5.0	211.3
60-101	28.1	1.2	1.1	32.0	108.6	4.9	184.3
101-130	34.1	18.4	7.4	30.6	99.0	4.2	193.7
130-165	36.1	1.2	6.4	29.2	78.0	3.9	167.8
165-220	44.0	23.2	17.3	22.1	70.2	4.2	181.0
220-260	33.2	2.2	3.1	20.6	69.6	3.6	156.7
Soils from shale (Bende)							
0-10	86.1	16.7	17.0	119.1	96.2	15.0	350.1
10-30	79.6	23.1	26.0	89.1	110.8	9.2	337.8
30-62	60.3	38.2	28.6	66.4	180.1	13.1	386.6
62-80	73.2	40.2	26.8	62.2	288.9	10.1	501.4
80-110	70.8	59.8	18.1	60.8	306.2	8.8	523.9
110-130	50.6	46.6	17.9	58.2	391.8	9.2	574.3
130-170	34.1	48.8	17.6	56.1	401.2	8.0	565.8
170-190	90.6	50.6	19.2	40.2	708.2	5.8	914.6
190-225	92.2	51.2	19.1	39.6	712.4	4.6	919.1
Soils from basement complex rocks							
0-6	78.6	75.4	2.9	89.1	19.2	21.6	286.8
6-11	76.4	72.1	2.0	88.2	18.1	21.2	278.0
11-36	66.2	22.2	3.1	84.6	17.4	19.6	203.1
36-50	42.4	29.6	20.6	66.4	72.6	23.8	255.4
50-90	31.8	23.1	8.1	58.6	105.3	25.6	252.5
90-150	28.6	36.6	11.8	32.3	69.6	16.7	195.6
150-170	27.4	34.4	10.2	32.1	65.3	16.6	186.0
Soils from cretaceous sandstone/shale (Ogoja)							
0-7	55.6	12.4	9.3	90.1	36.1	18.0	221.5
7-55	52.1	46.6	1.8	82.6	30.3	10.0	223.4
55-110	52.2	20.2	2.1	71.6	99.6	21.0	286.7
110-152	80.1	26.9	12.2	58.2	138.4	22.2	347.0
152-176	47.6	18.5	4.9	46.3	122.4	29.6	269.3
176-220	44.3	16.5	4.0	40.6	118.6	18.6	242.7
CV	10.1	13.6	2.6	44.2	52.5	14.3	58.3

Fe-P= Iron-phosphorus, Al-P = Aluminum-phosphorus, Ca-P = Calcium-phosphorus, Org-P = Organically bound phosphorus, Occ-P = Occluded phosphorus, Av-P = Available phosphorus, CV = Coefficient of Variation

Table 3: Variability in P-forms among soil groups (Ranking according to Aweto, 1982)

P-form	CV(%)	Ranking *
Fe-P	16.5	SV
Al-P	34.8	MV
Ca-P	11.2	SV
Org-P	52.6	HV
Occ-P	56.8	HV
Av-P	17.6	SV
Total-P	48.4	MV

SV = Slight Variation, MV = Moderate Variation, HV = High Variation

Apart from variabilities due to depth (Table 2), average values of P-forms among soil groups changed as shown in Table 3. Slight variation (CV = 16.5%) was recorded in Fe-P in the study site. The same trend occurred in the distribution of Ca-P and Av-P while Al-P and Total-P varied moderately (CV = 20-50% range). Highest variation (CV = 56.8%) was reported in Occ-P and Org-P (CV = 52.6%).

Relationship Between P-Forms and Selected Soil Properties

The P-forms were statistically related with some soil properties, namely clay, silt, sand and soil pH (Table 4). The significant relationship between P forms and soil pH is an asset in soil management

Table 4: Relationship between P-forms and some soil properties ($p \leq 0.05$)

Soil properties	P-form	r	r^2	n
Clay	Fe-P	0.70	0.49	30
Silt		0.40	0.16	30
Sand		0.10	0.01	30
pH		-0.60	0.36	30
Clay	Al-P	0.40	0.16	30
Silt		0.20	0.04	30
Sand		0.10	0.01	30
pH		-0.50	0.25	30
Clay	Ca-P	0.50	0.25	30
Silt		0.40	0.16	30
Sand		0.10	0.01	30
pH		0.70	0.49	30
Clay	Org-P	0.80	0.64	30
Silt		0.50	0.25	30
Sand		0.20	0.04	30
pH		0.30	0.09	30
Clay	Occ-P	0.90	0.81	30
Silt		0.40	0.16	30
Sand		-0.60	0.36	30
pH		0.50	0.25	30
Clay	Av-P	0.50	0.25	30
Silt		0.60	0.36	30
Sand		0.50	0.25	30
pH		-0.60	0.36	30
Clay	Total-P	0.50	0.25	30
Silt		0.20	0.04	30
Sand		0.10	0.01	30
pH		0.20	0.04	30

as status of soil pH can be used to predict P-availability and unavailability for crops. This is critical since P-anions react quickly with other ions to become less soluble even with slight pH change. Significant positive correlation ($p \leq 0.05$) was found between soil clay and P-forms, especially Occ-P, Org-P and Fe-P. Soil silt had very poor relationship ($p \leq 0.05$) with P-forms except with Av-P and Org-P while sand had non-significant relationship with most P-forms except Occ-P ($r = -0.60$).

DISCUSSION

The dominance of sand-sized particles in soils of the area is attributable to the influence of both climate and parent materials on their pedogenesis. High rainfalls and temperatures characteristic of the site promote weathering, mineralization, leaching and other pedogenetic processes of translocation, transformation, additions and losses. Consequently, soils become strongly to moderately acidic due to leaching irrespective of lithologic differences.

Higher values of Fe-P and Al-P over Ca-P is possibly due to higher acidity in soils of the study site. In acid soils, most solid phase phosphates are associated with Fe and Al while phosphates are associated with Ca in more basic soils (Isirimah *et al*., 2003). Dominance of Fe-P and Al-P is of immense of agronomic importance since cycling of their phosphates enhances high and continued phosphate availability in paddy soils.

Occluded P was the most abundant of P-forms in the studied soils and this could be due to greater adsorption of this unreactive form of P. This is in contrast to Org-P which was less in abundance than Occ-P in this study. In a Laboratory study, Frossard *et al.* (1989) noted that Org-P species, such as adenosine triphosphate, choline phosphate and glucose-6-phosphate were less strongly adsorbed onto soil particles than inorganic P. In contrast to the dominance of Occ-P over other P-forms, Turner and Haygarth (2000) reported the dominance of reactive P-forms over unreactive P-types in leachate from the grassland soils in England.

Abundance of Occ-P has some environmental implications, especially in leaching of P (Ron Vaz *et al*., 1993). It was reported that while reactive P-forms adsorb to soil micelle hence sustaining relatively lower losses (Frossard *et al*., 2000), Occ-P are easily transported in the soils (Toor *et al*., 2004). The Occ-P forms which are in particulate forms are not easily fixed, hence they are easily detached physically (Turner and Haygarth, 2000). The entrained Occ-P forms enter the water bodies where they cause eutrophication. Although P is considered relatively immobile in the soil system (Johnson *et al*., 1997), certain mechanisms make the soil P mobile by generally causing its leaching (Zhang *et al*., 2005).

Values of Av-P were low and relatively higher in soils derived from Basement Complex Rocks and a mixture of cretaceous sandstones and shale, higher pH-values in these soils could be responsible for greater availability of P in these soils. These results are consistent with the findings of Giesler *et al.* (2005) that pH influences soil P-sorption and availability of P in soils. In soils developed over coastal plain sands Av-P was very low in the sub-surface horizons, suggesting fixation by Fe and Al oxides and hydroxides (Sinaj *et al*., 2002) or losses from the soil system since sandiness confers macroporosity and less P retentivity. Using Bray II extractant, Unamba-Oparah and Kemakolam (1985) reported very low Av-P in the same region. There were generally slight to moderate variations in P-forms except for organic and occluded forms of P. Poor variation is possibly due to homogeneity in soil forming factors in the agroecology, with existing variabilities resulting from topography and land use (Akamigbo, 1999).

The P-forms related with some soil properties in this study. Significant ($p \leq 0.05$) positive relationship between soil clay and P-forms suggests preponderance of cations on clay surfaces which attract the negatively charged phosphate forms to the clay complex. Earlier, Sparks (2003) reported that Fe and Al oxides exist in soils as discrete crystals and coatings on clay and humic substances and as mixed gels, which play an important role in adsorption in soils. In addition to the above, clay has large specific surface area and reactivity. Other particle sizes had poorer relationships with P-forms, which could be as a result of the above reason.

However, Occ-P had a significant negative correlation ($p \leq 0.05$) with sand, implying that the sandier the soils, the less the Occ-P and this is reflected on the results of soils of Coastal Plain Sands. Soil pH had significant negative correlation ($p \leq 0.05$) with Fe-P and Al-P, meaning that increased pH does not favour abundance of these forms of P. Conversely, there was very significant positive correlation ($p \leq 0.05$) between Ca-P and soil pH, suggesting that higher pH values favour Ca-P precipitation. At lower pH, Fe and Al oxides are in abundance and these favour fixation of P while more alkaline soils would promote precipitation, fixation and abundance of Ca-P. These relationships can therefore change due to various transformations in the soil system (Shuai and Yost, 2004).

CONCLUSIONS

The study revealed that particle size distribution and soil pH influence the distribution of P-forms in soils of the agroecology. Again slight to moderate variations were recorded for some P-forms despite heterogeneity in lithologic materials. However, more detailed sampling is suggested for studies on modeling P-forms using soil properties as independent variables, as this would be necessary for monitoring these P-forms in soils and soil-related natural resources.

REFERENCES

Akamigbo, F.O.R., 1999. Influence of land use on soil properties of the humid agroecology of Southeastern Nigeria. Nig. Agric. J., 30: 59-76.

Aweto, A.O., 1982. Variability of upper slope soils developed under sandstones in Southwestern Nigeria. Nig. Geog. Tourn., 25: 27-37.

Edwards, D.R. and T.C. Daniel, 1993. Effects of litter application rate and rainfall intensity on quality of runoff from fescue grass plots. J. Environ. Qual., 22: 361-365.

FAO (Food and Agriculture Organization), 1998. Guidelines for Soil Profile Descriptions. 2nd Edn., Rome, pp: 66.

Frossard, E., J.W.B. Stewart and R.J.St. Arnaud, 1989. Distribution and mobility of phosphorus in grassland and forest soils of Saskatchewan. Can. J. Soil Sci., 69: 401-416.

Frossard, E., L.M. Candron, A. Oberson, S. Sinaj and J.C. Fardeau, 2000. Processes governing phosphorus availability in temperate soils. J. Environ. Qaul., 29: 15-23.

Gee, G.W. and D. Or, 2002. Particle Size Analysis. In: Methods of Soil Analysis. Dane, J.H. and G.C. Topp (Eds.), Part 4. Physical Methods. Soil Sci: Soc. Am. Book Series No. 5 ASA and SSSA, Madison, WI., pp: 255-293.

Giesler, R., F. Satoh, U. Ilstedt and A. Nordgren, 2004. Microbially available phosphorus in boreal forests: Effects of aluminum and iron accumulation in the humus layer. Ecosystem, 7: 208-217.

Giesler, R., T. Andersson, L. Lovgren and P. Persson, 2005. Phosphate Sorption in aluminum and iron-rich humus soils. Soil Sci. Soc. Am. J., 69: 77-86.

Hendershot, W.H., H. Lalande and M. Duquette, 1993. Soil Reaction and Exchangeable Acidity. In: Soil Sampling and Methods of Analysis. Carter, M.R. (Ed.), Can Soc Soil Sci., Lewis Publishers, London, pp: 141-145.

Isirimah, N.O., A.A. Dickson and C.A. Igwe, 2003. Introductory Soil Chemistry and Biology for Agriculture and Biotechnology. OSIA Int.'L Publishers Ltd, Port Harcourt Nigeria, pp: 36-97.

Johnson, G.V., W.R. Raun, H. Zhang and J.A. Hattey, 1997. Oklahoma Soil Fertility Handbook. 4th Edn., Department of Agronomy, Oklahoma State University, Stillwater, OK.

Lyons, J.B., J.H. Gorres and J.A. Amador, 1998. Spatial and temporal variability of phosphorus retention in a riparian forest. J. Environ., 27: 895-903.

Obi, M.E. and F.K. Salako, 1995. Rainfall parameters influencing erosivity in Southeastern Nigeria. CATENA 24:275-328. doi:10. 1016/0341-8162 (95) 00024-5.

Onweremadu, E.U., 2006. Application of Geographic Information Systems (GIS) on soils and soil-related environmental problems in Southeastern Nigeria. Unpublished Ph.D Thesis, University of Nigeria, Nsukka, Nigeria, pp: 479.

Orajaka, S.O., 1975. Geology. In: Nigeria in Maps: Eastern States. Oformata, G.E.K. (Ed.), Ethiope Publishing House, Benin Nigeria, pp: 7-9.

Ron Vaz, M.D., A.C. Edwards, C.A. Shand and M.S. Cresser, 1993. Phosphorus fractions in soil solution: Influence of soil acidity and fertilizer additions. Plant Soil, 148: 175-183.

Sharpley, A.N., 1997. Rainfall frequency and nitrogen and phosphorus runoff from soil amended with poultry litter. J. Environ. Qual., 26: 1127-1132.

Shuai, X. and R.S. Yost, 2004. State-space modeling to simplify soil phosphorus fractionation. Soil Sci. Soc. Am. J., 68: 1437-1444.

Sinaj, S., C. Stamm, G.S. Toor, L.M. Condron, T. Hendry, H.J. Di, K.C. Cameron and E. Frossard, 2002. Phosphorus exchangeability and leaching losses from two grassland soils. J. Environ. Qual., 31: 319-330.

Soil Survey Staff, 2003. Keys to Soil Taxonomy. 9th Edn., United States Department of Agriculture, pp: 332.

Sparks, D.L., 2003. Environmental Soil Chemistry. 2nd Edn., Academic Press, New York.

SPSS Inc., 1999. SPSS Base 10.0 Applications Guide. SPSS, Inc., Chicago, IL.

Tiessen, H. and J.O. Moir, 1993, Characterization of Available P in Sequential Extraction. In: Carter Soil sampling and Methods of Soil Analysis. Carter, M.R. (Ed.), Can. Soc. Soil Sci. Lewis Publishers, London, pp: 75-86.

Toor, G.S., L.M. Conron, H.J. Di, K.C. Cameron and B.J. CadeMenum, 2003. Characterization of organic phosphorus in leachate from a grassland soil. Soil Biol. Biochem., 35: 1317-1323.

Toor, G.S., L.M. Condron, H.J. Di and K.C. Cameron, 2004. Seasonal fluctuations in phosphorus loss by leaching from a grassland soil. Soil Sci. Soc. Am. J., 68: 1429-1436.

Turner, B.L. and P.M. Haygarth, 2000. Phosphorus forms and concentrations in leachate under four grassland soil types. Soil Sci. Soc. Am. J., 64: 1090-1099.

Unamba-Oparah, I. and C.E. Kemakolam, 1985. The effect of the soil solution ratio on the amount of available phosphorus extract from 18 soils of Southeastern Nigeria using Bray P-1 and Bray P-2 methods. Beit. Trop. Land. Veterin., 23: 373-384.

Wang, D. and D.W. Anderson, 1998. Direct measurement of organic carbon content in soil by Lew CR-12 Carbon analyzer. Commun. Soil Sci. Plant Anal., 29: 15-21.

Zhang, H., J.L. Schroder, J.K. Fuhrman, N.T. Basta, D.E. Storm and M.E. Payton, 2005. Path and multiple regression analyses of phosphorus sorption capacity. Soil Sci. Soc. Am. J., 69: 96-106.