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CHARACTERIZATION AND DISTRIBUTION OF PHOSPHORUS IN WEATHERED OXISOLS

OF ANWAI-ASABA, DELTA STATE, NIGERIA

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Abstract

A study was conducted in Anwai-Asaba area, Delta State, Nigeria aimed at assess the different chemical forms of Phosphorus. Phosphorus is one of the most limiting nutrient elements in the soil after nitrogen. Both field and laboratory studies were carried out. The field work involved profile, characterization delineation and auger soil sampling. Chemical analysis of soil samples was carried out to determine its physico-chemical properties, and including organic and inorganic forms of Phosphorus using appropriate procedures. Data collected were subjected to descriptive statistics and relationship between soil Phosphorus fractions and some soil physico-chemical properties established using simple correlation coefficient. Results of the study showed that the texture of the soils ranged from sandyloam and loamysand at the top soil surface to predominantly sandyclayloam in the lower pedogentic horizons. The initial chemical properties showed that the soils were strongly to moderately acid with a mean pH of 5.45. The organic carbon, total N, available Phosphorus, exchangeable bases and CEC were low depicting the inherent low fertility status of the pedons. The active Phosphorus forms were low with mean values of 6.24mgkg^{-1} for Fe-P, 5.46mgkg^{-1} for AL-P and 3.68mgkg^{-1} for Ca-P. The organic-P and Total-P were also low with mean values 6.68mgkg^{-1} and 21.32mgkg^{-1} Positive correlation existed between Fe_2O_3 and Al-P (0.668**) and available P (0.614**). Organic and Total Phosphorus also, correlated significantly with organic carbon (0.625** and 0.674**) indicating that Phosphorus in soil is mostly contained in organic forms.

Keywords: Characterization, distribution, chemical forms, Phosphorus, Oxisols, humid region.

Introduction

The Oxisols of the granitic basement complex are among the potential arable lands that are extensively cultivated in Nigeria (Agboola *et al*, 1997). They are mainly in the Southern rainforest and Mangrove regions of the country where rainfall exceed 1,200 mm per annum (Esu, 2004). Characteristically, these soils have poor structural stability, various nutrient imbalance, low activity clay, low inherent fertility and highly prone to human induced activities that could result to soil erosion (Agboola *et al*, 1997). Phosphorus has been identified as one of the most limiting nutrient elements after Nitrogen (Ahn, 1993). It is present in both organic and inorganic forms and undergoes both pedological and biological transformation. The biological transformation is important to short-term P availability, while the long-term Phosphorus availability is governed by pedological transformation (Agbenin, 1995).

The inorganic Phosphorus is classified into Fe-P, AL-P, Ca-P and occluded-P. They are related to the degree of chemical weathering and their sequence of dominance is: Ca-P, AL-P, Fe-P and occluded-P (Chang and Jackson, 1957 and Diamond, 1985). Regardless of the chemical identities of soil Phosphorus, the following release properties have been identified to control the supply of Phosphorus to plant roots. These are quantity (Labile or reserve P); Intensity (Concentration of soluble P); Capacity (constancy of solution P concentration) and Diffusion- (which is the movement of Phosphorus to roots through soil solution (Diamond, 1985).

Crop response to Phosphorus depends on soil characteristics. This is because the mobility of soil Phosphorus is controlled by its interaction with the soil matrix nutrients and amendments (Shaheen *et al*, 2009). It has been established that a large portion of phosphate added to tropical soils react with the soils in such a way that phosphate is made less soluble and less available for plant use (Konrad, 1997). As a result, the fate and efficiency of native and applied Phosphorus therefore remains one of the biggest problems in arable crop production in the tropics. This is because the availability of both applied and native Phosphorus is controlled largely by the sorption and desorption characteristics of the soil (Psado *et al*, 2004). These characteristics are influenced by the oxides, hydroxides and oxy-hydroxides of Al, and Fe and low activity clay components of the soils (Borggard, 1983).

In practical terms, Phosphorus transfer from solid to solution phases in a continuing depletion system (Plant sink) may be considered as dissolution of precipitated Phosphorus or as Phosphorus desorption. Therefore, the knowledge of the nature and distribution of soil Phosphorus is essential for understanding or estimating the availability of soil Phosphorus. The low inherent available phosphorous in oxisols can be linked to its high fixing capacity by sesquioxides. Phosphorus deficiency remains a major constraint to crop production in the sub-Saharan Africa. This is because the parent materials of these soils are low in Apatite bearing minerals thereby giving rise to soils low in native Phosphorus (Enwezor, 1989). Phosphorus availability is highly dependent on the forms it occurs in the soil. This is highly considered in making any good/proper fertilizer recommendation. The objective of this study is to characterize the different forms of Phosphorus, in oxisols of a humid area of Nigeria.

Materials and Methods

Description of the study area

The study was conducted in Anwai - Asaba. Anwai-Asaba is in Delta State, Nigeria. It is located between latitude 06° 14`N and longitude 06°49`E of the equator and lies significantly in a tropical rainforest zone with over 1,565 mm of rainfall per annum. The rainfall characteristic is bimodal in nature with peaks in July and September. The mean annual temperature is within 27.3°C. The annual relative humidity is about 65.7% (NIMET, 2011). Isohyperthermic temperature and udic moisture regions typify the general environment. The geology of the area is made up of coarse-grained pegmatites that is derived from basement complex that are more acid than base (Egbuchua, 2011). The general landscape is undulating with pockets of rolling topography. The vegetation is typical of the rainforest zone but have been systematically reduced to that of guinea savannah due to continuous cultivation. Agricultural practice here is based largely on rain fed and the dominant crops cultivated are mainly root and tuber crops.

Field work

Five (5) profile pits were dug within the transect and described according to FAO (2006) guidelines for profile description. The profiles were designated AW1 – AW5.

From each of the pedogenetic horizons of the profiles, soil samples were randomly collected for the determination of the physico-chemical properties of the pedons.

Sample preparation and laboratory analysis

The augered soil samples were air-dried in an ambient room temperature of 25°C for 3 days. Thereafter, they were crushed and sieved to pass through a 2 mm mesh sieve and properly labelled and well packaged for laboratory analysis of soil properties. All determinations were done following the procedures of soil and plant analysis Agbenin (1995). The particle size distribution was done by Bouyoucous hydrometer method using sodium-hexameta-phosphate (Calgon) as the dispersant. Soil pH was determined in a 1:1 water/soil ratio using digital pH meter. Organic carbon was determined by Dichromate wet-oxidation method, while total nitrogen was by micro-kjeldahl digestion method.

Initial available Phosphorus was extracted by Bray No 1 method. The exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M NH_4OAC (pH 7.0). The potassium and sodium in the leacheate were determined with column model 27 flame photometer, while calcium and magnesium by Atomic Absorption Spectrophotometer. The Cation Exchange Capacity (CEC) was determined by Ammonium acetate saturation method at pH 7.0 and the adsorbed ammonium ions displaced using acid – NaCl method. Al_2O_3 and Fe_2O_3 were extracted by the dithionite citrate-bicarbonate (DCB) Solution according to the methods of Menra and Jackson (1960). Total Phosphorus was determined using mixed acid of Hypochloric acid ($HCL0_4$), Nitric acid ($HN0_3$) and Sulphuric acid (H_2S0_4) digestion method (Agbenin, 1995). Organic Phosphorus was determined by the sequential extraction of the soil samples with concentrated H_2SO_4 and a dilute base (NaOH) as described by Bowman (1989). The inorganic phosphate (Ca-P, Fe-P and Al-P) were determined by fractionated method (Chang and Jackson, 1957). The Ca-P bound phosphate was later extracted using dilute acid fluoride while, Fe-P and Al-P were extracted by fluoride through the formation of complexes by Al and Fe. All determinations were done following the procedures of soil and plant analysis (Agbenin 1995).

Statistical Analysis

Descriptive statistics such as mean, standard deviation and coefficient of variation were employed for the characterization, while simple correlation coefficient was used to establish relationship between soil Phosphorus fractions and some physico-chemical properties of the soils.

Results and Discussion

Particle Size Distribution

The particle size distribution data in Table 1 showed that sand was the dominant fraction in all the soil profiles with a mean of 68.90% and a coefficient of variation of 11.12% which is least variable of the total profiles (Table 2). Values for the silt fractions ranged from 11 – 19% with a mean of 15.35% and a coefficient of variation of 15.70% which is moderately variable. The clay fraction on the other hand, increased with profile depth with no definite pattern of distribution. The values ranged from 6 – 28% with a mean of 15.70% and a coefficient of variations of 39.68% which is considered highly variable (Table 3).

Table 1: Percentage Distribution of various particle size classes in pedons studied

Horizon distinction	Depth (cm)	Sand	Silt %	Clay	Silt/clay	Text. class
Profile AW1						
AP	0-10	75	15	10	1.50	SL
Bt$_1$	10-25	75	11	14	0.79	SL
Bt$_2$	25-45	69	15	26	0.94	SL
Bt$_3$	45-70	59	15	16	0.58	SCL
Profile AW2						
AP	0-15	75	11	14	0.79	SL
AB	15-30	69	15	25	0.94	SL
Bt$_1$	30-55	58	17	16	0.68	SCL
Bt$_2$	55-70	55	17	28	0.61	SCL
Profile AW3						
AP	0-12	75	17	7	2.42	SL
AB	12-25	75	15	10	1.50	SL
Bt$_1$	25-45	69	15	16	0.94	SL
Bt$_2$	45-70	61	19	20	0.95	SCL
Profile AW4						
AP	0-15	81	13	6	2.17	LS
Bt$_1$	15-35	77	13	18	1.30	SL
Bt$_2$	35-55	65	17	10	0.94	SL
Bt$_3$	55-75	63	19	18	1.06	SL
Profile AW5						
AP	0-15	78	13	9	1.44	LS
Bt$_1$	15-35	74	14	12	0.07	SL
Bt$_2$	35-55	66	17	20	0.89	SL
Bt$_3$	55-75	61	19	19	0.95	SCL

Abbreviation: SL = Sandyloam; SCL= Sandy clay loam;
LS = Loamysand

The soils are coarse-textured. The texture ranged from sandy loam, loamysand to sandy clay loam. The sub-soil horizons were fairly rich in illuvial clay content which indicates a pedogenetic process of illuviation. The silt/clay ratio ranged from 0.07 – 2.42 (Table 1) with a mean of 1.07 and a coefficient of variation of 50.47 (Table 3) indicating highly variable. The highly variable nature of the silt/clay ratio may be related to the coarse-textured nature of the soil or, the resistant skeletal composition of the parent material (Brady and Weil, 2007).

Table 3: Cumulative mean, standard deviation and coefficient of variation values of some physico-chemical properties of the pedons studied

Soil Properties	$\bar{x}$	Std dev	CV (%)
Sand (%)	68.90	7.66	11.12
Silt (%)	15.35	2.41	15.70
Clay (%)	15.70	6.23	39.68
Silt/clay ratio	1.07	0.54	50.47
Soil pH (H_2O)	5.45	0.19	3.49
Org. C. (gkg^{-1})	6.32	0.58	9.18
Total N (gkg^{-1})	0.60	0.12	20.0
Avail. P. (mgkg^{-1})	6.25	0.86	13.76
Exchangeable bases (Cmolkg^{-1})			
Ca	2.58	0.09	3.49
Mg	0.62	0.09	14.52
K	0.14	0.04	28.57
Na	0.19	0.07	36.84
CEC (Cmolkg^{-1})	7.57	0.83	10.96
Fe_2O_3	151.14	56.89	37.64
Al_2O_3 (Mgkg^{-1})	115.81	40.42	34.90

Note: $\bar{x}$ = Mean
Std dev. = Standard deviation
CV% = Coefficient of variation

Chemical Properties

The pH of the pedons ranged from 5.25 – 5.85 which implied strongly to moderately acid. The high acid nature of the soil may result in nutrient depletion and fixation of Phosphorus in various forms. The organic carbon content within and across the individual pedons was low. The values ranged from 5.20gkg^{-1} to 7.25gkg^{-1} (Table 2) with a mean of 6.32gkg^{-1} and a coefficient of variation of 9.18gkg^{-1}. The low value could be attributed to water erosion, continuous cultivation resulting to paucity of vegetation cover and bush burning. Total nitrogen content was also low and below 1.5gkg^{-1} critical level as stated in FMANR, (1990). The low value may be due to low organic carbon content of the soil, crop uptake, continuous cultivation and the weathered nature of the pedons (Egbuchua, 2007).

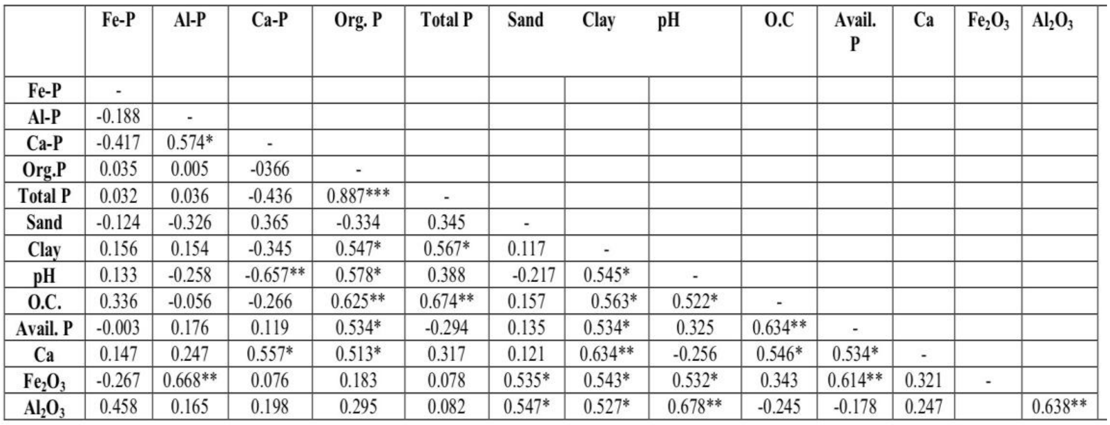
Table 4: Distribution of various forms of Phosphorus (mgkg^{-1}) in the pedons studied

Horizon distinction	Depth (cm)	Fe-P	Al-P	Ca-P Mgkg^{-1}	Org. P	Total P
Profile AW1						
AP	0-10	6.85	5.48	3.54	7.85	18.73
Bt$_1$	10-25	5.80	5.35	3.62	7.62	17.34
Bt$_2$	25-45	5.20	5.20	3.50	7.58	21.48
Bt$_3$	45-70	4.75	4.75	3.48	6.34	19.32
Profile AW2						
AP	0-15	7.20	5.35	3.28	6.95	22.78
AB	15-30	6.75	5.42	3.61	6.80	22.58
Bt$_1$	30-55	6.38	5.38	3.45	6.48	21.13
Bt$_2$	55-70	5.47	5.25	3.52	5.85	20.09
Profile AW3						
AP	0-12	7.40	5.68	3.39	6.54	23.01
AB	12-25	6.35	5.76	3.43	6.72	22.26
Bt$_1$	25-45	6.21	5.58	3.51	6.53	21.83
Bt$_2$	45-70	5.75	4.72	3.48	6.40	20.35
Profile AW4						
AP	0-15	6.45	5.75	3.47	6.38	22.05
Bt$_1$	15-35	6.38	5.85	3.52	6.35	22.10
Bt$_2$	35-55	6.24	5.64	3.48	6.45	21.81
Bt$_3$	55-75	5.58	5.73	3.25	6.32	20.88
Profile AW5						
AP	0-15	6.75	5.62	3.75	6.45	22.57
Bt$_1$	15-35	6.60	5.60	3.62	6.40	22.22
Bt$_2$	35-55	6.48	5.65	3.48	6.75	22.36
Bt$_3$	55-75	5.72	5.72	3.65	6.84	21.93
Mean values		**6.24**	**5.46**	**3.68**	**6.68**	**21.32**
Std deviation		**0.68**	**0.31**	**0.81**	**0.50**	**1.52**
CV%		**10.90%**	**5.68**	**22.01**	**7.49**	**7.13**

The initial available Phosphorus content was also low. The values ranged from 5.20 – 7.35mgkg^{-1} with a mean of 6.25mgkg^{-1} and a coefficient of variation of 13.76% (Table 3). The low content of Phosphorus under acid condition could be attributed to P-fixation by oxy-hydroxides of Fe and Al (Egbuchua, 2007). According to Tsado *et al*, (2006), Hassan and Raji, (2006) and Egbuchua (2011), Phosphorus fixation by sesquitic materials has been the major factor of Phosphorus depletion in the tropics.

The exchangeable bases (Ca, Mg, K and Na) across the pedons were low with mean values of 2.58cmolkg^{-1} for Ca; 0.62cmolkg^{-1} for Mg; 0.14cmolkg^{-1} for K and 0.19cmolkg^{-1} for Na respectively (Table 3). The relatively low content of the exchangeable cations is a reflection of the intensely weathered nature of the parent material and the kaolinitic nature of the mineralogy (Egbuchua, 2011).

Table 5: Simple correlation coefficient between soil Phosphorus fractions and some soil phyisco-chemical properties in the pedons studied



	Fe-P	Al-P	Ca-P	Org. P	Total P	Sand	Clay	pH	O.C	Avail. P	Ca	Fe_2O_3	Al_2O_3
Fe-P	-												
Al-P	-0.188	-											
Ca-P	-0.417	0.574*	-										
Org.P	0.035	0.005	-0366	-									
Total P	0.032	0.036	-0.436	0.887***	-								
Sand	-0.124	-0.326	0.365	-0.334	0.345	-							
Clay	0.156	0.154	-0.345	0.547*	0.567*	0.117	-						
pH	0.133	-0.258	-0.657**	0.578*	0.388	-0.217	0.545*	-					
O.C.	0.336	-0.056	-0.266	0.625**	0.674**	0.157	0.563*	0.522*	-				
Avail. P	-0.003	0.176	0.119	0.534*	-0.294	0.135	0.534*	0.325	0.634**	-			
Ca	0.147	0.247	0.557*	0.513*	0.317	0.121	0.634**	-0.256	0.546*	0.534*	-		
Fe_2O_3	-0.267	0.668**	0.076	0.183	0.078	0.535*	0.543*	0.532*	0.343	0.614**	0.321	-	
Al_2O_3	0.458	0.165	0.198	0.295	0.082	0.547*	0.527*	0.678**	-0.245	-0.178	0.247		0.638**

*, ** and *** = Significant at 1% and 5% levels of probability

The extractable Fe_2O_3 and Al_2O_3 contents ranged from 78.35mgkg^{-1} to 235.17mgkg^{-1} and 75.10mgkg^{-1} to 210.10mgkg^{-1} respectively. These values are quite high for the study area (FMANR, 1990). It is also in conformity with the findings of Schwertmann (1995) who attributed it to crystallization of iron and aluminium oxides as inhibited by organic matter and clay content.

Active-P forms

Active Phosphorus which are Phosphorus associated with Fe; Al and Ca. are presented in (Table 4).

Results showed that Fe-P ranged from 5.85mgkg^{-1} to 13.25mgkg^{-1} with a mean of 6.24mgkg^{-1} and a coefficient of variation of 10.90%. And Al-P ranged from 7.35mgkg^{-1} to 10.35mgkg^{-1} with a mean of 5.46mgkg^{-1} and a coefficient of variation 5.68%. Also, Ca-P in the pedons ranged from 3.28mgkg^{-1} to 3.75mgkg^{-1} with a mean of 3.68mgkg^{-1} and a coefficient of variation of 22.01% (Table 4). The values are high for phosphate associated with Fe and Al but low for P associated with Ca. This can be vividly explained by the highly weathered nature of the parent material from which the soils evolved and the acidic nature of the soil. The low content of basic cation of calcium in the study area was responsible for the low phosphate content associated with Ca. This accession was evidenced from high free iron and aluminium oxides (Fe_2O_3 and Al_2O_3) of the soils. The same findings have been reported by Hassan and Raji (2006) in some basement complex soils of Nigeria.

Organic-P

These are the inorganic Phosphorus in soil solution immobilized by the microbial and plant biomass in most weathered soil. The availability of Phosphorus in soils is essentially governed by organic-P-mineralization (Agbenin, 1995 and Brady and Weil, 2007).

The result of the study (Table 3) showed that the values ranged from 6.35mgkg^{-1} to 7.85mgkg^{-1} with a mean of 6.68mgkg^{-1} and a coefficient of variation of 7.49%. The content of organic matter is said to be low across the pedons thereby, depicting the low status of organic-P in the soils. According to Hassan and Raji (2006), the easily soluble fraction of soil organic-P are often the most important factor in supplying Phosphorus to plants in highly weathered soil. Therefore, Organic-P in soil is the main source of Phosphorus for plants grown in highly weathered soil.

Total-P

The total-P content of the soils ranged from 17.34mgkg^{-1} to 23.01mgkg^{-1} with a mean of 21.32mgkg^{-1} and a coefficient of variation of 7.13% which is least variable (Wilding and Dress, 1983). The values are low reflecting the low inherent P-status of the soil and the high tendency of P-fixation by oxy-hydroxides. The same views have been buttressed by Hassan and Raji (2006) Tsado *et al.* (2006) and Shaheen *et al*. (2009).

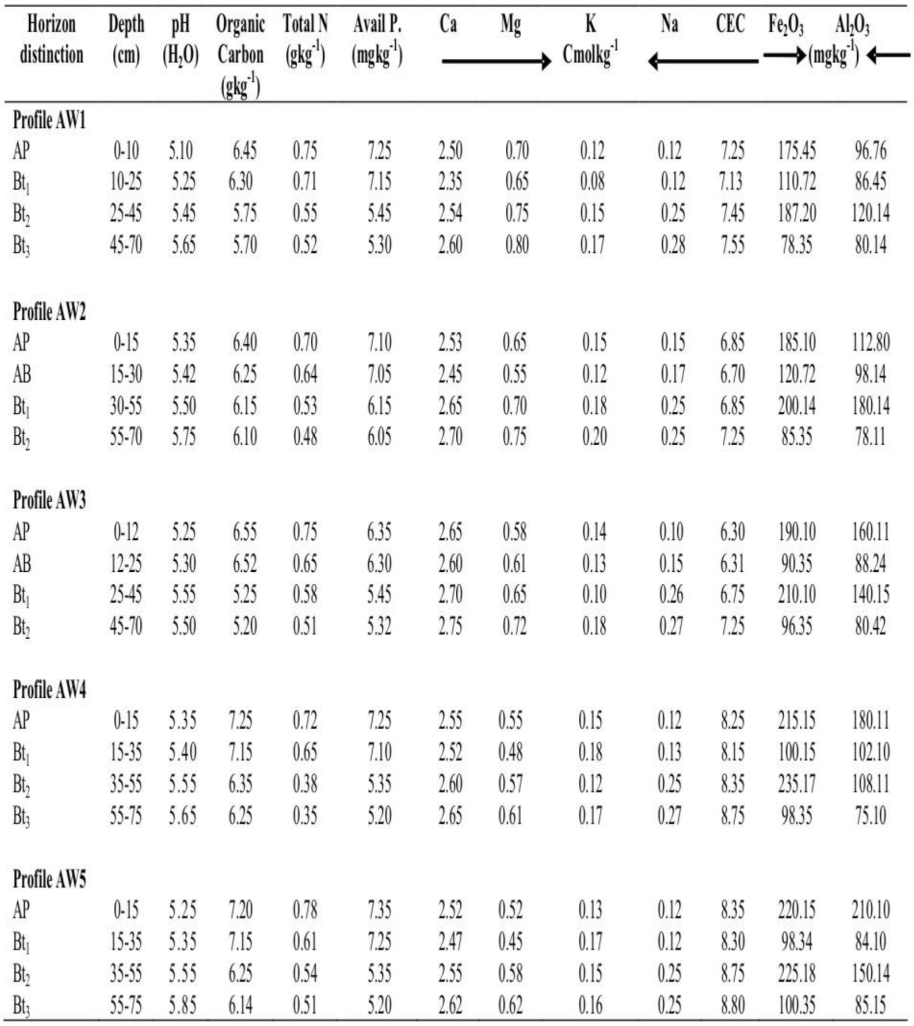
Correlation Coefficient

The simple correlation coefficient between soil Phosphorus fractions and some soil properties in Table 5 showed that positive correlation was found to exist between Fe_2O_3 and Al-P (0.668**) and available-P (0.614**). Also, Al_2O_3 correlated positively with Fe_2O_3 (0.638**) but negatively with organic carbon (-0.245). Available Phosphorus also correlated positively with organic carbon (0.634**). The interpretation of this is that high content of iron-Fe-oxides in the soil could cause serious P-fixation in the various pedons. This affirmed the findings of Uzu *et al*. (1975); Tekalingn *et al*. (1991); Hassan and Raji (2006) and Tsado *et al*. (2006) in their various Phosphorus studies. Their findings were strongly pined to the fact that in highly weathered soils, Phosphorus availability is bound to be low due to P-fixation. Similarly, the positive correlation between available Phosphorus with organic carbon was an indication that bulk of the soluble P comes from organic matter mineralization. Organic and Total Phosphorus had significant correlation with organic carbon (0.625** and 0.674**) respectively indicating that Phosphorus in soils is mostly contained in organic form. The negative and non-significant relationship that existed among Phosphorus forms and some soil properties in some cases were due to the inherent low fertility status of the pedons and other anthropogenic factors. This fact was supported by the findings of Hassan and Raji (2006) in some soils of Nigerian basement complex.

Conclusion

Results of the study showed that weathered oxisols were dominantly sandy in the surface horizon and generally coarse-textured. The soils were generally acidic, high in Fe and Al-oxides which indicate high sorption capacity of Phosphorus in the pedons and low in inherent fertility. The active forms of Phosphorus (Fe-P), (Al-P) and (Ca-P) as well as the organic and total Phosphorus ranged from low to moderate. Both positive and negative correlations were found to exist between different forms of Phosphorus and some soil properties. However, the bulk of available P in the soil comes from organic matter mineralization. The study however calls for copious Phosphorus fertilizer application and liming for optimum and sustainable crop production. The application must however, be based on soil test value.

Table 2: Some Chemical Properties of Soil Samples in Pedons studied



Horizon distinction	Depth (cm)	pH (H_2O)	Organic Carbon (gkg^{-1})	Total N (gkg^{-1})	Avail P. (mgkg^{-1})	Ca	Mg ⟶	K Cmolkg^{-1}	⟵ Na	CEC	Fe_2O_3 ⟶ (mgkg^{-1})	⟵ Al_2O_3
Profile AW1												
AP	0-10	5.10	6.45	0.75	7.25	2.50	0.70	0.12	0.12	7.25	175.45	96.76
Bt_1	10-25	5.25	6.30	0.71	7.15	2.35	0.65	0.08	0.12	7.13	110.72	86.45
Bt_2	25-45	5.45	5.75	0.55	5.45	2.54	0.75	0.15	0.25	7.45	187.20	120.14
Bt_3	45-70	5.65	5.70	0.52	5.30	2.60	0.80	0.17	0.28	7.55	78.35	80.14
Profile AW2												
AP	0-15	5.35	6.40	0.70	7.10	2.53	0.65	0.15	0.15	6.85	185.10	112.80
AB	15-30	5.42	6.25	0.64	7.05	2.45	0.55	0.12	0.17	6.70	120.72	98.14
Bt_1	30-55	5.50	6.15	0.53	6.15	2.65	0.70	0.18	0.25	6.85	200.14	180.14
Bt_2	55-70	5.75	6.10	0.48	6.05	2.70	0.75	0.20	0.25	7.25	85.35	78.11
Profile AW3												
AP	0-12	5.25	6.55	0.75	6.35	2.65	0.58	0.14	0.10	6.30	190.10	160.11
AB	12-25	5.30	6.52	0.65	6.30	2.60	0.61	0.13	0.15	6.31	90.35	88.24
Bt_1	25-45	5.55	5.25	0.58	5.45	2.70	0.65	0.10	0.26	6.75	210.10	140.15
Bt_2	45-70	5.50	5.20	0.51	5.32	2.75	0.72	0.18	0.27	7.25	96.35	80.42
Profile AW4												
AP	0-15	5.35	7.25	0.72	7.25	2.55	0.55	0.15	0.12	8.25	215.15	180.11
Bt_1	15-35	5.40	7.15	0.65	7.10	2.52	0.48	0.18	0.13	8.15	100.15	102.10
Bt_2	35-55	5.55	6.35	0.38	5.35	2.60	0.57	0.12	0.25	8.35	235.17	108.11
Bt_3	55-75	5.65	6.25	0.35	5.20	2.65	0.61	0.17	0.27	8.75	98.35	75.10
Profile AW5												
AP	0-15	5.25	7.20	0.78	7.35	2.52	0.52	0.13	0.12	8.35	220.15	210.10
Bt_1	15-35	5.35	7.15	0.61	7.25	2.47	0.45	0.17	0.12	8.30	98.34	84.10
Bt_2	35-55	5.55	6.25	0.54	5.35	2.55	0.58	0.15	0.25	8.75	225.18	150.14
Bt_3	55-75	5.85	6.14	0.51	5.20	2.62	0.62	0.16	0.25	8.80	100.35	85.15

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