PEDOLOGICAL STUDY OF SOILS DEVELOPED FROM CRETACEOUS SEDIMENTS OF EZE-AKU SHALE GROUP IN YALA LOCAL GOVERNMENT AREA, CROSS RIVER STATE, NIGERIA.

***Uquetan, U. I., *Abua, M. A., *Essoka, P. A., **Osang, J. E., **Egor, A. O.**
*Department of Geography and Environmental Science,
University of Calabar, Calabar, Nigeria.
Email: uquetanuquetanibor@gmail.com & jonathanosang@yahoo.com
Contact: 07034653641

** Department of Physics,
Cross River University of Technology, Calabar, Nigeria.

ABSTRACT: Detailed pedological characterization of soils developed from cretaceous sediments of Eze-Aku shale group in Yala Local Government Area, Cross River State, Nigeria was carried out. The soils varied from sandy loam to sandy clay loam to clay in texture. The soil structure varied from weak fine granular to moderate medium sub-angular blocky, the soil consistence was friable under moist condition, the bulk density ranged from 1.28 to 1.49gcm3. Water content 13-18kpa in pedon 1, 3, 4 and 28-55KPa in Pedon 2. The soils are strongly acidic (pH 5.0-5.6) and non-saline. Organic carbon content (<2.0) and total Nitrogen (0.04-0.28) were rated moderate while available P and exchangeable cations were low to moderate (2.42mgkg). Effective cation exchange capacity and sulphur content of the soil was low. Base saturation was moderate above 60 percent. Availability of Fe, Mn, Cu and Ni is sufficient to sustain arable cropping while Cadium, Cobalt and Zinc availability is low. The mineralogy showed mixed clay mineralogy dominated by Kaolinite (1:1 clay mineral) and illite (2:1) clay mineral. However, traces of other minerals such as Wiserite, Kyanite, Nacrite, Geothite, Antase, and Haemitite were also recorded. The upland soils were classified as Typic Kandiustults (USDA) or Haplic Acrisol (FAO/UNESCO), while Upper slope soils as plinthic Kandiustults or Dystric Plinithosols and the Flood plain soils as Vertic fluaquents or Dystric Gleysols. The study therefore recommend: crop residue management, constant organic manure inputs and mineral fertilizers as keys to replenishing nutrient mining of these soils.

Keywords: Cretaceous sediments of Eze-Aku Group, Shale, Pedogogical properties, classification, mineralogy.

———————————— ◆ ————————————

INTRODUCTION

The nature of underlying parent material has profound influence on soil development and invariably soil characteristics. Parent materials determines the kind of clay, texture, K and P content, and to a large extent the morphological characteristics of a given soil (Young, 1976; Faniran and Areola, 1978; Akimigbo and Asadu 1983; Olatunji, 2007; Essoka, 2008; Uquetan, 2013). The physico-chemical characteristics of soils depend largely on the composition of their inorganic fractions (Ogun Kunle, 1993; Weddivira et al., 2000). The proportion of bases in the exchange complex and the pH also depends on the texture and mineralogical composition of the soil fraction, similarly, the mineralogy of the fine and coarse fractions plays a significant role in the structure, porosity, expansion-contraction processes and water retention properties of the soil (Combardelle et al., 1994; Abe et al., 2010). Furthermore, studies carried out by Chikezie et al., (2010), Igwe et al., (1999), Kpamwang et al., (2004), Abe et al., (2009), Esu and Moberg (1991), Donahue et al., (1983) reported significant relationship between parent material and mineralogical properties. The upland soils of Yala are deep, well drained and coarse textured in the surface while the lowland soils are deep, poorly drained and fine textured. The lowland soils are easily flooded and are used for paddy rice cultivation.

Several studies have been carried out on the soils developed on sandstones and shale in southeastern Nigeria, (Jungerious, 1964; Floyd, 1969; Eshett, 1987; Igwe et al., 1999, Fasina et al., 2005; Akamigbo and Asadu, 1983). Regrettably, little is known about this extensive and important agricultural soils of Yala Local Government Area, Cross River State. The objective of this study was to characterize the soils in terms of morphological, physico-chemical and mineralogical properties for improved agricultural production and to augment the national database of soil resources.

MATERIALS AND METHODS

Study Location

The study area is located in Yala Local Government Area, Cros River State, Nigeria. The study area lies approximately between Latitude $6^0$42'N and $6^0$48'N and Longitude $8^0$45'E and $8^0$49'E. The climate is typically humid tropical with marked dry and rainy seasons, the former being longer than the later. The annual rainfall ranges from 1750mm to 2000mm with peaks in June – July and September – October. Mean temperature ranges between 27^0C and 35^0C.

Field study and description

Two soil profile pits each were dug along the North South transect, East transect, West transect and distant locations on fallow lands that have not been cropped for at least two years. The pedons were described and sampled according to the established procedures of the USDA (NRCS) guidelines for profile description (Soil Survey Staff, 2002). Soil samples were collected from pedogenic horizon identified, while undisturbed core samples were also collected for the determination of bulk density at interval of 500m along North-South East, West transects and from distant location which was 1km away from North-South transect. The soil samples were air dried, sieved through a 2mm sieve and taken to soil science laboratory of Federal University of Agriculture, Makurdi, Nigeria for detailed laboratory analysis. Mineralogical properties were analysed at Beijing Centre for Physical and Chemical Sciences, China.

Laboratory Procedures

Particle size analysis was carried out by the hydrometer method (Gee and Bauder, 1986). The bulk density was determined as described by Bowles (1992). pH was determined in water at a soil, liquid ratio of 1:2 (Thomas, 1996). Electrical conductivity was determined using the conductivity meter (Model WTWLF 90). Total nitrogen was determined by Kjeldahl digestion, (Bremner and Mulvancy, 1982), Organic Carbon by (Walkley and Black) and Available Phosphorus (Bray and Kurtz, 1945), exchangeable acidity in the extract measured with IMKCL solution and the acidity in the extract measured by titration with 0.01MNaoH. Exchangable bases was extracted with neutral $IMNH_4OA_C$, pH 7.0. Exchangeable Potassium and sodium in the extract were determined using a flame photometer (IITA, 1979) while exchangeable Calcium and Magnesium was determined using atomic absorption spectrometer. Percentage base saturation was calculated as the sum of all bases divided by ECEC and multiplied by 100. Heavy metals (Copper, Zinc, Iron, Manganese, Chromium, Nickel, Lead and Cobalt) were determined following the methods described by Udo et al., (2009). The mineralogy fractions was characterized by x-ray diffraction technique (Whittig and Allardice, 1986, Buri, 1999). The relative intensities of XRD peaks were used to quantify each clay mineral type (Alexiodes and Jackson, 1996; Moore and Reynold, 1997).

RESULTS AND DISCUSSIONS

Morphological characteristics

Table 1 gives the morphological data of the representative pedons. The soils in pedon 1 are formed from uniform parent materials as shown by the almost uniform distribution of the sand fraction. The profile are deep and well drained (>150cm). The hue is very dark brown to dark brown (10YR 3/2 to 7.5YR 4/4) throughout the upper 20cm and strong brown to light grey (7.5YR 5/8 to 5YR 7/1) in the lower horizons. It has an ochric epipedon that is about 20cm thick with a texture of sandy loam to gravely sandy clay loam. The structure is of medium to weak fine sub-angular blocky, slightly sticky and slightly plastic (wet) firm (moist). There is also preponderance of pedovites throughout the B-horizon. These pedons represents the upland soils of Yala.

Pedons 2 are soils that occupy the major extensive flood plains in the study area. The soils are deep (>100cm) and poorly drained at the middle of the floodplain, but shallow

(>50cm) or moderately deep at lower depressions. Most of the rice fields are found adjacent to Okpauku river and adjoining streams. The top soil consists of medium textured sandy clay loam overlying fine textured clay sub-soils. Transported sediments occur over a material weathered from clay shale which generally underlies the area. The structure is of weak fine crumb to moderate medium subangular blocky. The underlying materials which form clay shale residiuum, has a hue of 10 YR 6/4 to 5YR 7/1) throughout. The soil is very sticky and plastic when wet, the profile is mottled from 40cm depth indicating poor drainage. Pedon 3 represent soils in the upper slopes. The soils are well drained, dark reddish brown (2.5YR 5/8) to dark grey (2.5YR 4/6) sandy clay loam at the sub-surface. The soils had moderate medium sub-angular blocky structure and generally friable moist consistence. Clay and Fe-oxyhydroxide cations were quite obvious on pedofaces and in pores.

Pedon 4 consist of soils from distant locations. A typical soil profile representing the soils showed a layered soil formed on transported sediments of sandstones origin occurring over clay shale which generally underlines the area. The sandy mantle has a hue of 10YR to 5YR (moist), a texture of gravelly sandy clay, a weak time crumb structure to moderate medium sub-angular blocky, a moist friable consistence common petroplinthic modules and a clear and smooth boundary with the underlying horizon. The mantle has an Ochric epidedon that is about 26cm thick and a B-horizon that has patchy clay films on faces of peds. There is a good high clay content in the soil. Mica flakes and quartz were also identified within the horizon with iron and manganese modules at the subsurface soils.

Physical properties

The particle size distribution of the soils (table 2) shows total size distribution of sand is 56-65%, clay fractions vary from 31-38%, the texture varies from sandy loam to sandy clay loam to clay, while silt content is less than 8%. The clay content at the surface can be attributed to clay migration or surface erosion by runoff or a combination of both (Malgiwi et al., 2000). The dominance of sand in pedon reflects the parent material of the soil. The soils in pedon 2 are poorly drained, plastic and sticky. There is increase in clay with depth due to lluviation-illuviation processes. While soils in pedon 3 are well-drained, dark reddish brown sandy loam, at the surface. Total sand constitutes 23-51% clay fractions vary from 22-49% while the silt content ranged from 17.0-33.0%. Soils in pedon 4 are typical soils with gravelly sandy clay texture. The water content at field capacity ranged 13-18 in pedon 1, 3 and 4 and 28-55 in pedon 2. The results shows that pedon 2 soil retains more water than pedon 1, 3 and 4 due to the extensive flood plain and higher clay content. The Bulk density varies from 1.37 to 1.47 in pedon 1, 3 and 4 and 1.28gcm^{-3} in pedon 2. The higher bulk density in pedons 1, 3

ISSN 2229-5518

and 4 soils relative to pedon 2 soil may be due to the gravelly nature of pedons 1, 3 and 4 the possibility of migrating clay filling up the pore spaces in the will structured Bt horizon (Idoga and Azagaku, 2005).

Chemical properties

The chemical properties of the soils are presented in Table 2. The soil pH ranging from 5.0 to 5.60. This indicates that the soils are strongly acidic in reaction and shows that significant amounts of exchangeable Al^{3+} and H^{+} are present to affect plant growth (Udo et al, 2009; Schoneneberger et al., 2012). Such soil conditions can induce phosphate fixation and reduce the ability of micro-organisms to fix atmospheric nitrogen. Electrical conductivity (EC) values were low (0.025-0.08dsm^{-1}). These soils are non-saline as the values are below 4dms-1. Organic carbon contents vary from 0.98 to 2.94%, with most surface mean values above 1%. The soils are therefore rated medium in organic carbon contents as most values are below 2.0% (FPDD, 1990). Total Nitrogen range between 0.04-0.28% with surface mean values greater than 0.109. This further implies that the profile distribution of N is highly correlated with that or total C in the four pedons. Available P is low (2.42mgkg^{-1}) with values below 10mgkg^{-1} for all samples. Although the flood plains contains a higher amount of available P than other pedons. These values are low for most productive soils (Holland et al., 1989). The exchangeable cations; Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} ranges between Cmolkg^{-1}, 0.35-0.90CmolKg^{-1}, 0.10-0.30Cmolkg^{-1} and 0.09-0.30Cmolkg^{-1} respectively in the surface soils. These values decreased with soil depth and are rated as low to moderate (Enwezor et al., 1989; Haby et al., 1990; Obigbesan, 2009; Holland et al., 1989). Effective cation exchange capacity (ECEC) ranged 1.49 to 3.88Cmolkg^{-1}. These values indicate that the soils are highly weathered, highly leached and the dominance of kaolinite in the soils. The percentage base saturation ranged from 47.5 to 78.1%, this is rated medium probably because the roots of the vegetation in the study area has concentrated the base it shallow depths. Available S varied from 3.2 to 5.8mgkg. These values are rated low below the critical levels (5-20mgkg-1). This suggest that organic matter is the mean source of sulphur. Organic matter inputs and crop residue management are keys to replenishing S in the soil.

The mean values of heavy metals are summarized in table 3. The values of heavy metals were within the safe range encountered in tropical mineral soils (Brady and Weil, 1996). All the other heavy metals showed moderate levels of availability across the pedons except for Zn (4.10-5.84) which was very low, Fe (139-217.8mgkg^{-1}, Mn 54.0-68.4mgkg^{-1}, Cd 0.12-1.04mgkg^{-1}, Pb 0.38-0.96mgkg^{-1}, and Co 0.47-2.0mgkg^{-1} respectively. Except for available Cu, heavy metal availability shows a decreasing trend. This can be attributed to the lower organic matter content and soil pH, as heavy metal availability and toxicity is greatly governed by soil pH. Although the current availability of Fe, Mn, Cu and Ni is sufficient to sustain arable crop farming, further crop intensification in some areas may cause deficiency problems in the future.

MINERALOGY

Table 4 presents the x-ray diffraction (XRD) results of the clay fractions of the soils. indicate that quartz (22.1-38.9), Kaolinite (19.2-26.5%), Illite (20.4-25.0), wiserite (6.7-16.0), kyanite (6.1-10.3), Nacrite (0.8-1.98), Geotite (5.6-8.0%), Anatase (3.2-4.1) and Haemitite (2.24-2.6) respectively. The mineralogy of clay-sized particles showed a mixed mineralogy dominated by kaolinite (1:1) clay mineral. A consensual relationship existed between kaolinite and illite. Quartz remains the most dominant resistant sand mineral in the soil with a high probability of co-existence with kaolinite. The presence of illite, wiserite, kyanite and Nacrite shows that the soils contains some weatherable minerals of pedological importance; while the presence of nacrite indicated that the soils were dominated by low activity clays. It could be assumed that the weathering of minerals in these soils was strongly influenced by high rainfall and temperature that had a significant impact on the weathering of feldspar and mica that played a significant role in the mineralization of kaolinite, illite, wiserite and kyanite that are important clay minerals for food crop production in the tropics. The results agrees with previous studies reported by Igwe et al., (1999), Buri et al., (2000), Abe et al., (2006), Abe et al., (2010) and Fernandes et al., (2011).

SOIL CLASSIFICATION

The characteristics of the four representative pedons were used to classify the soils in the USDA soil taxonomy (soil survey staff, 1975) and with approximate correlation in the FAO/UNESCO soil map of the world legend (Rome, 1990). Soils in pedon 1 are classified as Typic Hapludults (USDA). This correlates approximately to HaWWWplic Acrisol using the FAO/UNESCO soil map. The soils in pedons 2 serve as major paddy fields in the study area. They are classified as vertic flauquent (soil survey staff, 1992) or Dystric Gleysol (FAO/UNESCO, 1988), due to the absence of diagnostic horizons, aquic conditions for some months of the year, warm soil temperature, organic carbon content above 0.29%, presence of cracks during the dry season. Soils in pedon 3 are classified as Typic hapludult (USDA) and haplic Acrisol (FAO/UNESCO) while soils in pedon 4 are classified as Plinthic Kandiustult (Dystric Plinthosol) because of the presence of Plinthite at depth of 116-126cm.

CONCLUSION

The results obtained in this study indicate that the examined soils are generally deep (ranging between 100 and 150cm) except for pedon 2 and dark brown in colour with moist hue of 10YR to 7.5YR in pedon I, 10YR to 5YR in pedon 2, 5YR to 2.5YR in pedon 3 and 10YR to 5YR in pedon 4. Soil structure varies from weak fine to moderate medium sub-angular blocky. The subangular structures suggest that the soil promote good aeration and drainage and hence can support agriculture. The texture of the soil varied from sandy loam to sandy clay especially for surface layers and sandy clay loam to clay for subsurface layers. The bulk density of the soil was generally low and equally supportive of agronomic activities. The soils were strongly acidic and low in organic carbon, total Nitrogen, Avaialable P and exchangeable bases, implying low inherent fertility of the soils that would require amendments to adequately support productive agronomic use. However, most of the micro-nutrients: Fe, Mn, Cu and Ni is sufficient to sustain arable crop farm were within critical levels to sustain arable crop farming, exception of Zn, Cd and Cb. Clay mineralogy showed mixed clay mineralogy dominated by kaolinite (1.1 clay mineral). A consensual relationship existed between kaolinite and illite (2:1 clay mineral).

The study therefore, recommended constant organic inputs, crop residue management, and application of mineral fertilizers as keys to replenishing nutrient mining on these soil and improve crop yield. Minerals like goethite, Anatase and haemitite were shown in both fine sand and clay mineralogy of the soils.

TABLE 1

Morphological properties of the representative pedons

Profile Code	Depth (cm)	Colour	Textual Class	Structure	Consistence	Boundary	Inclusions
P_1	0-15	10YR $^3/_2$	SL	1msbk	WSS, mfr	cs	Coated quartz grains
	15-32	10YR $^6/_2$	SCL	2msbk	WSS, mfr	gs	Pedovites
	32-69	7.5YR $^5/_8$	SCL	2msbk	WS, mfi	ds	Pedovites
	69-119	7.5YR $^7/_1$	C	2msbk	WS, mfi	ds	Pedovites
P_2	0-15	10YR $^6/_4$	SCL	1msbk	WSS, mfi	GS	Artificats
	15-29	7.5YR $^5/_4$	SC	1msbk	WVS, mfi	GS	Mottling
	29-60	5YR $^7/_1$	C	1msbk	WVS, mfi	GS	Plinthitic nodules
	60-87	5YR $^6/_2$	C	1msbk	WVS, mfi	GS	Common slikensides
P_3	0-15	5YR $^3/_4$	SL	2msbk	WSS, mvfr	CS	Coated quartz grains
	15-43	7.5YR $^3/_2$	SCL	2msbk	WSS, mfr	DW	Pedovites
	43-92	5YR $^5/_8$	SC	3msbk	WVS, mfi	DW	Petroplinthic modules
	92-140	2.5YR $^4/_6$	SC	3msbk		DS	Common Slickensides
P_4	0-15	10YR $^3/_4$	SC	1fcg	WSS, mfr	GS	Petroplinthic modules
	15-49	10YR $^4/_1$	C	2mcg	WSS, mfr	GS	Petropinthic modules

	49-83	10YR $^5/_2$	C	2msbk	WSS, mfi	CS	Common slickensides
	83-160	5YR $^4/_6$	C	2msbk	WVS, mfi	DS	Large common slickensides

Texture: G=gravelly, L=loam, S=sand, C=clay. **Structure:** 1,2,3=weak, moderate and strong, f,m,c=fine, medium and coarse; gr=granular, sbk=sub-angular blocky structure. **Consistence:** w=wet, m=moist, ss=slightly sticky; s=sticky; fr=friable; fi=firm, v=very; **Boundary:** CS=clear smooth; ds=diffuse smooth; gs=gradual smooth; dw=difuse wavy.

TABLE 2

Physico-chemical properties of the soils

Profile Horizon	Depth (cm)	pH	Ec (dsm^{-1})	Orge (%)	Total N (%)	Avail. P ($mgkg^{-1}$)	S $Mgkg^{-1}$	Exchangeable base ($cmolkg^{-1}$)				EA	ECEC ($cmolkg^{-1}$)	Base Sat. (%)	Sand (%)	Silt (%)	Clay (%)	Bulk Density	Water contents of the soils	
								Ca	Mg	K	Na									
Pedon 1	**Typic Kandiustults (Haplic Acrisols)**											**Distant Upland**							**33kpa**	**1500kpa**
AP	0-15	5.6	0.056	2.68	0.14	8.84	5.30	2.30	0.9	0.3	0.2	1.0	2.89	78.7	46.0	22.0	32.0	1.41	13.00	8.5
Bt	15-30	5.6	0.062	2.42	0.10	5.20	4.00	2.00	0.8	0.2	0.18	1.5	2.12	7.9	39.0	27.0	34.0		13.8	9.3
Bt_1	32-69	5.4	0.068	1.84	0.09	5.80	3.60	1.80	0.5	0.15	0.12	1.7	1.51	60.2	30.0	32.0	38.0		15.5	11.6
Bt_2	69-118	5.2	0.072	1.26	0.05	5.60	3.2	1.60	0.4	0.19	0.15	1.4	1.67	62.6	21.0	33.0	46.0		18.0	13.2
Pedon 2	**Vertic fluaquent (Dystric Glysol)**											**West flood plain**								
AP	0-15	5.4	0.052	2.94	0.24	9.60	4.20	2.40	0.8	0.2	0.18	1.00	3.58	78.2	40.0	25.0	35.0	1.28	28.0	20.0
Bt	15-29	5.4	0.058	2.76	0.20	8.20	4.00	2.20	0.6	0.18	0.14	1.40	2.23	69.0	35.0	23.0	42.0		37.2	29.5
Bt	29-60	5.3	0.072	2.45	0.16	6.00	3.75	2.00	0.5	0.12	0.19	1.00	2.81	74.3	30.0	28.00	42.0		18.4	31.0
Bt_1	60-87	5.0	0.080	2.08	0.09	5.10	3.14	1.90	0.35	0.08	0.04	1.60	1.48	47.5	20.0	31.00	48.0		58.0	34.3
Pedon 3	**Typic Kandiustults (Haphic A Crisols)**																			
AP	0-15	5.6	0.035	2.20	0.199	9.24	4.9	2.00	0.9	0.25	0.3	1.20	2.88	77.5	42.0	17.0	41.0	1.37	13.8	8.2
Bt	15-43	5.5	0.048	1.75	0.12	8.60	4.4	1.80	0.7	0.20	0.2	1.40	2.07	61.7	33.0	20.0	47.0		15.0	9.0
Bt_1	43-92	5.4	0.056	1.21	0.07	6.50	4.1	1.65	0.6	0.24	0.19	1.40	1.91	65.3	31.0	27.0	42.0		15.4	10.8
Crt_3	92-140	5.2	0.063	1.10	0.04	6.0	3.6	1.84	0.4	0.18	0.20	1.50	1.75	48.3	20.0	29.0	51.0		17.6	12.4
Pedon 4	**Plinthic Kandiustult (Dystric Plinthosol)**											**North – South Upper Slope**								
Ap	0-15	5.4	0.025	1.62	0.17	8.40	4.5	2.20	0.8	0.2	0.17	1.0	3.37	77.1	38.0	20.0	42.0	1.49	14.0	8.6
Bt	15-49	5.3	0.043	1.40	0.12	6.20	4.2	2.00	0.7	0.15	0.15	1.3	2.31	69.8	33.0	21.0	46.0		14.5	9.7
Bt_1	49-83	5.2	0.054	1.10	0.09	5.70	3.7	1.70	0.9	0.10	0.09	1.5	1.86	59.4	27.0	24.0	49.0		15.4	10.8
Crtg	83-160	5.0	0.06	0.98	0.06	5.00	3.4	1.60	0.5	0.10	0.18	1.4	1.98	62.0	23.0	27.0	50.0		16.7	11.3

TABLE 4

Micro Nutrient Contents in soils of the study area

Profile	Micro Nutrient Contents (mgkg^{-1})							
Horizon	**Zn**	**Fe**	**Mn**	**Cu**	**Ni**	**Cd**	**Pb**	**Co**
Pedon 1	5.10	154.8	68.4	3.4	1.72	1.18	0.92	1.90
	4.64	172.0	61.6	3.0	1.68	0.82	0.62	1.62
	4.28	180.4	57.3	2.8	1.44	0.33	0.62	1.62
	4.10	211.2	54.0	2.5	1.20	0.16	0.48	0.96
Pedon 2	4.40	188.6	63.0	3.6	1.68	1.64	0.77	2.0
	4.36	192.0	60.7	3.2	1.72	1.30	0.82	1.80
	5.28	204.2	57.5	3.1	1.52	0.90	0.60	1.34
	4.20	218.0	55.3	2.8	1.10	0.48	0.38	0.60
Pedon 3	4.80	139.0	65.6	3.5	1.55	1.02	0.94	1.94
	4.52	143.5	62.4	3.0	1.32	1.14	0.60	1.52
	4.48	169.6	57.9	2.7	1.26	0.42	0.45	0.96
	4.24	203.8	54.2	2.4	1.00	0.21	0.83	0.47
Pedon 4	5.84	165.8	66.2	3.4	1.80	1.02	0.88	2.00
	5.26	1.88.2	61.0	3.6	1.50	0.60	0.76	1.64
	5.02	201.6	58.4	2.9	1.64	0.24	0.51	1.30
	4.68	217.8	55.7	2.6	1.42	0.12	0.38	0.98

TABLE 4

Mineralogical properties of soils (wt%)

Soil Pedons	Particle Size	Quartz	Kaolinite	Illite	Wiserite	Kyanite	Nacrite	Goethite	Anatase	Ha
Upland	Fine sand	38.9	24.52	25.0	-	-	-	5.6	3.6	2.38
Lowland	Clay	22.1	26.5	23.9	8.96	6.9	0.8	.2	3.2	2.24
Flood plain	Fine sand clay	24.7	19.2	20.4	11.0	8.5	1.9	8.0	4.7	2.6

REFERENCES

Abe, S. S., Buri, M. M., Issaka, R. N., Kiepe, P., & Wakatsuki, T. (2010). Soil fertility potential for rice production. *Journal of Agricultural Research quarterly*. 44(4), 343 – 355.

Abe, S. S., Masunaga, T., Yamamoto, S., Honna, T., &Wakatsuki, T. (2006). Comprehensive assessment of clay mineralogical composition of lowland soils in West Africa. *Soil Science and Plant Nutrition*, 52, 479 – 488.

Akamigbo, F. O. R., & Asadu, C. L. A.(1983). Influence of Partial Materials on Soils of Southeastern Nigeria. *East Africa Agricultural Journal*, 48; 81 – 91.

Alexoides, C. A., & Jackson, M. L. (1996). Quantitative Clay Mineral Analysis of Soils and Sediments. *Clays and Clay minerals*, 14: 35-53.

Bowles, J. E. (1992). Engineering properties of soils and their measurements. (4th ed.) McGraw Hills. Boston, pp.241.

Brady, N. C. & Weil, R. R. (2002). *Elements of the nature and properties of soils*. 2nd edition. New Jersey: Pearson Education Inc.

Bray, R. H. & Kurtz, L. T. (1945). Determination of total, organic and available forms of Phosphorus in soils. *Soil Science* 59:39-45.

Bremmer, J. M. & Mulvancy, C. S. (1982). Total Nitrogen In: L. A. Page (ed), methods of soil analysis. *Agron. Monograph of American Soc. Agrons Madison*, Vol. 2. 595-622.

Buri, M. M., Masunaga,T., & Wakatsuki, T. (1999). Soil of flood plains of West Africa: General fertility status. *Soil Science and Plant Nutrition*, 45:37 –50.

Cambardella, C. A., Moorman, T. B., Parkin, T. B., Karlen, D. L., Turco, R. F. and Konokpa, A. E. (1994). Field scale variability of soil properties in central Iowa soils. *Soil Sci. Am. J.* 58:1501-1511.

Chikezie, I. A., Eswaran, H., Asawalam.,D.O.& Ano, A.O. (2010). Characterization of two benchmark soils of contrasting parent materials in Abia State, Southeastern Nigeria.*Global Journal of Pure and Applied Science* 16(1) 23 – 29.

Donalue, R. L., Miller, R. W. and Schickluna, J. C. (1983). An introduction to soils and plant growth (5th edition). Prentice Hall Inc. Englewood Cliffs. New Jersey. 667.

Enwezor, W. O., Ohiri, A. C., Opuwaribo, E. E. & Udo, E. J. (1989). Review of fertilizer use in crops in Southeastern Nigeria. *Fertilizer Procurement and Distribution*, Lagos, Nigeria. p.420.

Eshett, E. T. (1987). The Basaltic soils of southeastern Nigeria: Properties, Classification and constraints to productivity. *Journal of Soil Science*.38:565—571.

Essoka, P. A. (2008). Soil variation over basement complex rocks and slope position im a part of Central Cross River plain, Southerh Nigeria. Ph.D Thesis, Department of Geography, ABU, Zaria.

Esu, I. E. (1999). *Fundamentals of pedology*. Stirling: Horden Publishers (Nig.) Limited. 66-68.

Esu, I. E., & Moberg, I. P. (1991). Clay mineralogical composition of three vertisol pedons developed on different parent materials in northeastern Nigeria. *Nigeria Journal of Soil Science. 10*,25 -46.

Fagbami, A. (1976). The soil and Agro-environment of the Ibadan area. Department of Agronomy, University of Ibadan, pp.263.

FAO/UNESCO (2010). World reference base for soil resources. A framework for international classification, correlation and communication. Rome.

Farniran, A. and Areala, O. (1998). *Essentials of soil study with special reference to tropical areas*. London: Heineman Education Books Limited.

Fasina, A. S. Aruleba, J. O. Omodayo, F. A. Omotoso, S. I. SluHill, O. S. (2005). Evaluation of potential of soil soils for crop production at Ado-Ekiti, Southwestern Nigeria. *Journal of Soil Science,* 15(2):16-20.

Fernandes, M. F., Barreto, A. C., Mendes, I. C., & Dick, R. P. (2011). Short-term response of physical and chemical aspects of soil quality of a kaolinitic Kandiudalfs to agricultural practices and its association with microbiological variables. *Agriculture, Ecosystems and Environment 142 . 419– 427.*

Fertilizer Production, Distribution and Division (FPDD) (1990). Literature Review on soil fertility Investment in Nigeria published by Federal Ministry of Agriculture and Natural Resources, Lagos. pp.281.

Floyd, B. (1969). Eastern Nigeria. A geographical review. London: Macmillan Company Limited. 67-119.

Gee, G. W. & Bauder, J. W. (1986). Particle size analysis. p. 384-411. In: Klute, A. (eds). Methods of Soil Analysis. Part 2. 2nd ed. *Agronomy monograph, 9. ASA and SSSA*, Madison, WI.

Harby, V. A. Rusette, M. P. and Skogley, E. O. (1990). Testing soils for potassium, Calcium and Magnessium. 181-227. In: Westmaster, R. L. (ed). Soil testing and plant analysis, 3rd ed. SSSA. Madison: Washington DC.

Holland, M. D., Allen, V. G, Barton, D., & Murphy, S. T. (1989). Land evaluation and Agricultural Recommendations of Cross River National Park, Oban Division prepared by ODNRI in collaboration with WWF for Federal Republic of Nigeria and the Cross River State.

Idoga, S. & Azagaku, D. E. (2005). Characterization and classification of soils of Janta Area, Plateau State of Nigeria. *Journal of Soil Science,* 15:116-122.

Igwe, C. A., Akimigbo, F.O.R. & Mbagwu, J.S.C. (1999). Chemical and mineralogical properties of soils in Southeastern Nigeria in relation to aggregate stability. *Geoderma*, 92:111-123.

IITA (1979). *Selected methods in soil and plant analysis*. Manual series No. 1. International Institute of Tropical Agriculture, Ibadan. Nigeria, 76.

Jungerius, P. D. & Levelt, T. W. M. (1964). Clay mineralogy of soils over sedimentary rocks in Eastern Nigeria. *Soil Science, 97*:89-95.

Kparmwang, T. Characterization and classification of Basaltic soils in the Northern Guinea Savanna at zone of Nigeria. Unpublished Ph.D. Thesis. Department of Soil Science, ABU, Zaria. 176.

Malgwi, W. B., Ojanuga, A. C., Chude, V. O., KParmwang, T. K., & Raji, B. A. (2000). Morphological and physical properties of some soils of Samaru, Zaria, *Nigerian Journal of Soil Research,* 1:58-64.

Nelson, M. J. and Sommers, L. E. (1982). Total Carbon, Organic Carbon and Organic Matter, In: Page, L. A. Miller, R. H. and Keeney, D. R. (eds), *Methods of Soil Analysis*, 539-579. Part 2. *Chemical and Microbiological Methods* (2nd ed).

Obigbesan, G. O. (2009). Ratings for soil fertility classes in Nigeria. Personal communication.

Olatunji, O.O., Ogunkunle, A.O., & Tabi, F. (2007).Influence of parent material and topography on some soil properties in southwestern Nigeria. *Journal of Soil and Environmental Research. 7*: 1-6.

Orunkule, A. O. (1993). Variation of some properties along two toposequence on Quartzite Schist and Banded gneiss in southwestern Nigeria. *Geo Journal*, 30(40):399-402.

Schoeneberger, P. J., Wysocki, D. A., Benham, E. C. (2012). Field book for describing and sampling soils. Version 3.0 NRCS-NSSC, Lincoln, N. E. pp.300.

Soil Survey Staff (1993). *Soil Survey Manual*. Soil Conservation Service. USDA, Handbook No. 18 2nd edition. US Government Printing Office, Washington DC. USA.

Soil Survey Staff (2006). Soil taxonomy. A Basic system of soil classification for making and interpreting soil surveys. 10th edition. USDA Agricultural Handbook No. 436.

Thomas, G. W. (1982). Exchangeable cations. In: Page, A. L., Miller, R. H. and Keeney, D. R. (eds). *Methods of Soil Analysis*. Part 2 Agron. 9 Madison, Washingtong DC. 159-165.

Thomas, G. W. (1996). Soil pH and soil acidity. In: D. L. Sparks (ed.). Methods of soil analysis. Part 3 – Chemical methods. *Soil Science Society of America*. Book Series 5. Madison, Wisconsin. pp 475-490.

Udo, E. J., Ibia T. O., Ogunwale, A. O. & Esu I. E. (2009), *Manual of Soil, Plant and Water Analysis.* Sibon Books Ltd. Lagos – Nigeria.

Uquetan, U. I. (2013). Soil quality assessment for lowland rice production in Obubra local government area, Cross River State, Nigeria. Ph.D Thesis. Department of Geography and Environmental Science, University of Calabar, Nigeria.

Whittig, L. D. & Allardice, W. R. (1986). X-ray Diffraction techniques. In: Arnold Klute (ed.). pp.331-362. *Methods of soil analysis*, Part 1- Physical and mineralogical methods, SSSA Book Series 5, Madison, Wisconsin, USA.

Wuddivira, M. N. Store, R. J. and Ekwue, E. I. (2009). Clay organic matter and wetting effects on splash detachment and aggregation breakdown under intense rainfall. *Soil Science Society of American Journal*. 73:226-232.

Young, A. (1976). *Tropical Soils and Soil Survey*. Cambridge: Cambridge University Press. pp.426.