International Journal of

Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 8 (3): 107-122, 2013
ISSN 1816-4897 / DOI: 10.3923/ijar.2013.107.122

Characterization and Classification of Onwu River Floodplain Soils in Cross River State, Nigeria

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ABSTRACT

The aim of this study was to determine the morphological, physicochemical and mineralogical properties of Onwu river floodplain soils at Akraba in Yala, Cross River State, Nigeria. Floodplain soils have great agricultural potentials and should be utilized for crop production. Two soil units were identified and designated as Akraba I (AK I) and Akraba II (AK II). Five soil profiles were dug with two in the AK I and three in the AK II soil units respectively. The soils were mapped and characterized by hues of 10-2.5 YR, low chroma (≤2), soil reaction (pH 4.5-5.2), organic carbon (12.9-37.0 g kg^{-1}), available P (4-5 mg kg^{-1}), base saturation (55-94%), minerals such as quartz, illites and nacrites as well as kaolinite-montmorillonite in AK II soil unit. Others were sand (>766.0 g kg^{-1}) in the surface of AK I and clay (>34.0 g kg^{-1}) in the subsurface of AK II soil unit. Based on the criteria of the USDA Soil Taxonomy, the AK I and AK II soil units were classified as Typic kandiudults, Coarse, Loamy, Siliceous, Isohyperthermic and Fluvaquentic Humaquepts, Fine clayey, Mixed isohyperthermic, respectively. Equivalent FAO-UNESCO units were Haplic acrisols and Gleyic/Vertic Cambisols, respectively. The internal pedogenic processes such as illuviation and gleization dominated AK I and AK II soil mapping units, respectively. The AK II soil unit was at variance with the AK I soil unit in terms of high fertility status, poor drainage and presence of kaolinite-montmorillonite. Generally, the soils are suitable for crop production.

Key words: Characterization, classification, floodplain soils, Onwu river, agricultural production

INTRODUCTION

The Onwu river floodplains at Akraba, Yala Local Government Area of Cross River State is gently undulating from the upland to nearly level in the active floodplains. The soils in the floodplains are submerged for about two to three months (July to September), while the adjoining elevated land is wet in the rainy season. The soils have low water table below, 2 m in the dry season. The parent materials, drainage and topography have been reported to influence the morphological, physicochemical and mineralogical properties of the soils (Ogbaji, 2010; Akpan-Idiok *et al*., 2012). Two geomorphic/physiographic units such as Akraba I (AK I) and Akraba II (AK II) have been identified in the vast floodplain (Ogbaji, 2010). The soils consist of admixture of colluvial-alluvial deposits with greater amount of alluvial materials giving rise to textural classes of sandy loam to clay in the floodplains and loamy sand to sandy clay loam in the elevated landscape. Soils of the floodplain have been characterized by moderate to high contents of basic cations, organic carbon, moderate to strong acidity and rated moderate to high in fertility status (Ogban and Babalola, 2009; Ogbaji, 2010; Hossain *et al*., 2011; Ukabiala, 2012).

Worldwide, floodplains soils are useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants. The soils are also used for aquaculture (Sheriff *et al.*, 2008; Nagabhatla and van Brakel, 2010). About 12 million hectares of floodplain have been put into agriculture in Africa. In west Africa, about 47% of floodplain soils have been put to rice cultivation, while about 65,783 hectares of floodplains constituting about 7.2% of total land area have been identified in Nigeria (Ojanuga *et al.*, 2003; Wakatsuki, 2004). In Cross River State of Nigeria, about 79,995 hectares have been identified and most of the soils are useful for agricultural production especially in areas where the flood level is low enough for rice cultivation during the rainy season (Akpan-Idiok, 2012). Studies have shown that physicochemical and mineralogical properties of floodplain soils are essential for sustainability classification of the soils for crop production (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Ayalew and Beyene, 2012). Furthermore, mineralogical study helps in the evaluation of mineralogical impacts on soil productivity, mineral transformation, degree of soil development and classification of soils at the family level under USDA Soil Taxonomy (Hossain *et al.*, 2011). Akpan-Idiok and Antigha (2009) classified floodplain soils in Northern Cross River State of Nigeria as Vertic fluvaquents and Fluvaquentic humaquepts under USDA soil classification system. The equivalents of the soils under World Reference Base of Soil Resources were Dystric gleysols or Gleyic cambisols.

Characterization of Onwu river floodplain soils is important as this would enable evaluation of the soil their potentials for effective agricultural production. As the human population is increasing at an alarming rate in the state, there is pressing need to boost food production by utilizing available land resources. The data generated from this study would equip floodplain users, with necessary information that would be essential for the management of the floodplain soil for sustainable agriculture and environment. This study reports some salient morphological, physicochemical and silt-clay mineralogy of two geomorphic soil units from the Onwu river floodplains in Yala Local Government Area of Cross River State, Nigeria.

MATERIALS AND METHODS

The field study and the laboratory analyses took place between April-July, 2009. The Onwu river floodplain (6°43'18" and 6°45'59" N; 8°37'21" and 8°38'55" E) is located at Akraba-Itekpa in Yala Local Government Area of Cross River State, Nigeria (Fig. 1). The area falls within the Southern Guinea Savanna Ecological zone of Nigeria (Keay, 1959). The geology consists of weathered shale and sandstone formations. The area is characterized by a mean annual rainfall of 1750-2000 mm, a mean annual temperature of 27-28°C, a mean relative humidity of 50 to 60% (Bulktrade Investment Company Limited, 1989).

Field study: The land area (480 ha) with two geomorphic units designated as Akraba I (AK I) and Akraba II (AK II) was mapped using GERMIN model of Geographical Positioning System (GPS). The surveyed area of AK I at elevation of 49 m occupy 112 ha, while the surveyed AK II soil unit at elevation below 49 m above a mean sea level covers 370 ha. The soil mapping units (AK I and AK II) were examined in the field to properly adjust the interpretive landform or geomorphic boundaries and soil units in the landscape. Field observation of auger samples was done at a distance of 200 m. Five soil profile pits were dug with two in Akraba soil unit I (AK I) and three in Akraba II (AK II). The morphological characteristics of each of the profile pits were described, after which, bulk soil samples were collected for laboratory analysis. Soil profile descriptions followed the pattern outlined in the Soil Survey Manual (Soil Survey Staff, 2010).

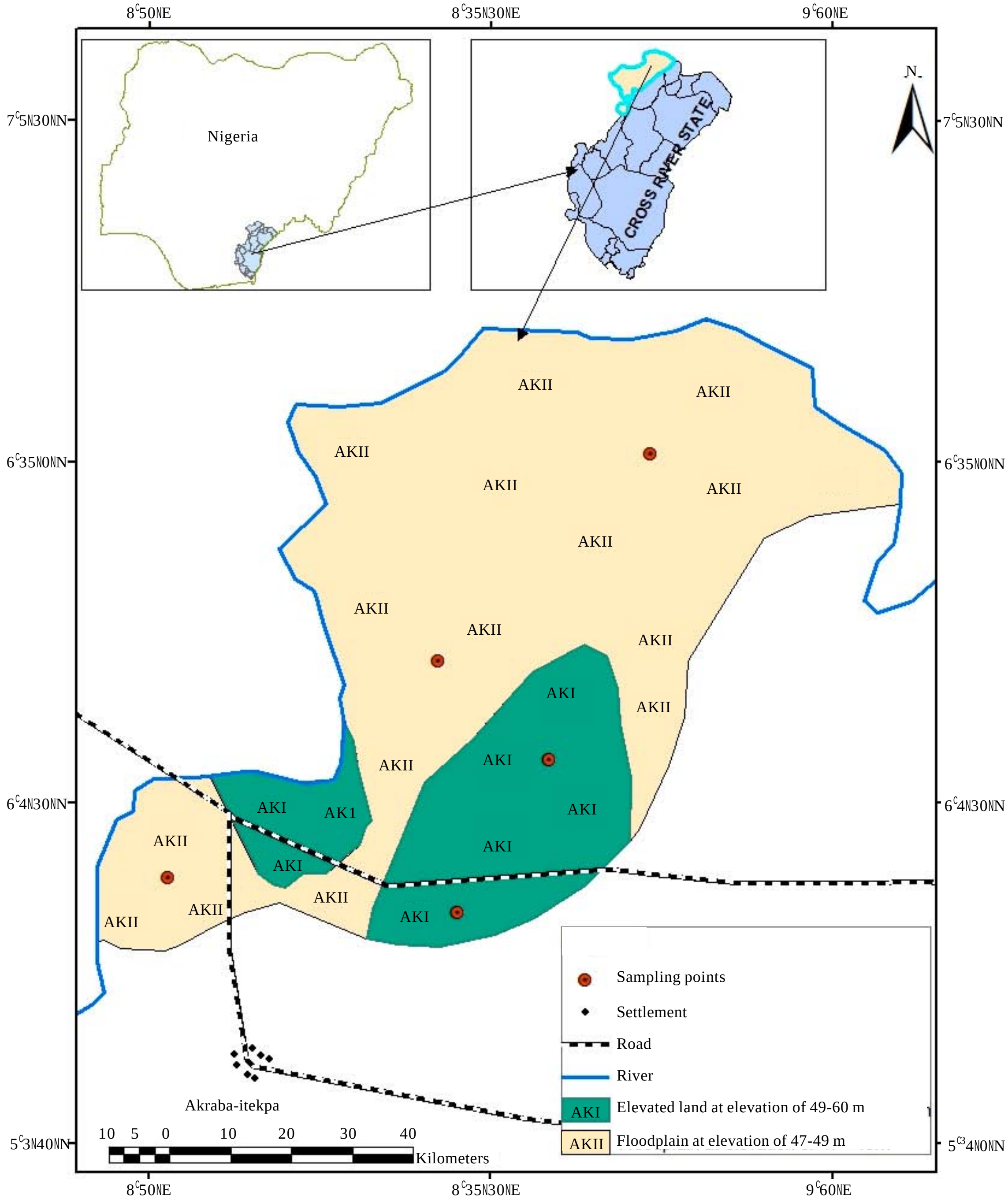


Fig. 1: Soil map of Onwu river floodplain showing sampling points at Akraba-Itekpa, Yala Local Government Area, Cross River State, Nigeria

Laboratory studies: Soil samples were air-dried and passed through a 2 mm sieve. Particle size was carried out by Bouyoucos (1951) hydrometer method. Soil pH was determined potentiometrically after the equilibration with water in 1:2 soil/liquid ratio and electrical conductivity was measured in 1:2 saturation extract (Udo *et al*., 2009). Organic carbon was determined by the Wakley-Black method (Allison, 1965). Total nitrogen was determined by the Micro-Kjeldhal Method (Bremner, 1965) and Bray No. 1 method was used for extraction of phosphate, while the ammonium molybdate-blue method was used for determining the extractable phosphate (Bray and Kurtz, 1945). Exchangeable Ca, Mg, K and Na were extracted by leaching with IN NH_4OAc (pH 7.0). Ca and Mg were determined by atomic absorption spectrophotometry, while Na and K were determined by flame emission spectrophotometry. Exchangeable acidity was extracted with IN KCl and the acidity in the extract was determined by titration with 0.05 NaOH (McLean, 1965). Cation Exchange Capacity (CEC) was determined by IN NH_4OAc (pH 7.0) saturation followed by the displacement of the absorbed NH^+_4 by Na^+ (Chapman, 1977). The powder samples (silt-clay fraction-<0.05 mm) were obtained by sieving through 53 μm mesh were subjected to X-Ray Diffraction (XRD) analysis (Chen *et al.*, 2001) with a Bruker AXS Diffractometer, Model D8 using monochromatic CuKα radiation in Beijing Centre for Physical and Chemical Analysis, Beijing People Republic, China.

Statistical analysis: Descriptive statistics with the help of SPSS software were used for data analysis.

RESULTS AND DISCUSSION

Morphological properties: The morphological properties of the five profiles representing soils in two geomorphic soil mapping units namely: Akraba soil unit I (AK I) and Akraba soil unit II (AK II) are presented in Table 1. The soils consist of old deposits of alluvial materials and are well-developed, imperfectly or well-drained with deep profiles and have Ap horizons with a range in thickness of 22 to 29 cm. The soils are characterized by sandy loam to sand clay loam texture; matrix colour with chroma >2 and weak medium subangular blocky ped of sticky consistence in the surface. Clay bulge and skins reflecting illuviation process occur at the depth of 22 to 75 cm within the profiles. This is an indication that the soils have undergone intensive weathering and are therefore old soils classified as Ultisols under USDA Soil Taxonomy. On horizon delineation, the soils on elevated and stable land have a unique sequence of clearly developed soil horizons from the surface downward and are designated Ap-Bt1-B2-C (Table 1). Similar characteristics were obtained for coastal plain soils of Calabar, Nigeria (Akpan-Idiok and Ukwang, 2012). A modal soil profile consists of very dark brown (10 YR 3/2) sandy loam surface overlying red (2.5 YR 4/6 or 2.5 YR 5/8) sandy clay loam. The soil unit covers about 112 hectares and is a good agricultural land for cultivation of yam (*Dioscorea rotundata*), maize (*Zea mays*), melon (*Citrullus lanatus*) among others.

The soils are derived from weathered shale and colluvial materials and are flooded during the rainy season. The soils are characterized by sandy loam or loam to sandy clay loam or clay loam texture; grey colour matrix of chroma less 2 and hues of 10 YR to 2.5 YR in most horizons, suggesting that the soils have aquic moisture regime for some months in the year. Gleization is therefore the dominant pedogenic process in the profiles. Similar characteristics were observed in inland valley bottom on Basement complex in sub-humid south western Nigeria (Ogban and Babalola, 2009). A typical soil profile of Akraba soil unit II (AK II) consists of a black (10 YR 2/1) sandy loam surface over grey (10 YR 5/1) or reddish grey (2.5 YR 6/1) clay loam, sandy clay or clay with abundant quantities of variously coloured mottles prominent in the subsurface profiles (Table 2). The alternate wetting and drying conditions in these soils resulted in the reduction and subsequent release of iron oxides which were accumulated in the form of strong brown, brown and

Table 1: Morphology and classification of AK I soil mapping unit of Onwu river floodplain, Akraba-Itekpa, Yala Local Government area, cross river state

Profile No./Location	Horizon	Depth (cm)	Colour	Mottles	Texture	Structure	Consistence	Boundary	Remarks
AK I (Pedon 1): Typic kandiudult, coarse loamy siliceous isohyperthermic (USDA)/Haplic acrisol (FAO)									
06°44'10" N 008°37'47" E	Ap	0-22	10YR 3/2, vdb	nm	sl	ifmgr	wnsp	cs	Many fine and medium roots
Elevation 60 m	Bt1	22-65	2.5YR 4/6, r	nm	scl	1msbk	wsp	gs	Common fine roots, many micro pores, clay films
	B2	65-109	2.5YR 5/8, r	nm	scl	1msbk	wsp	ds	Few fine roots. Common micro pores
	C	109-150	2.5YR 5/8, r	nm	scl	1fsbk	wvsp		
AK I (Pedon 2): Typic kandiudult, coarse loamy siliceous isohyperthermic (USDA)/Haplic acrisol (FAO)									
06°44'10" N 008°37'38" E	Ap	0-29	10YR 3/2, db	nm	sl	1fmgr	wssp	cs	Many fine roots, many macro and micro pores, many ants,
Elevation 49 m	Bt1	29-75	10 YR 4/3, b	nm	l	1msbk	wsp	gs	Common fine roots, many macro and micro pores, few fine and medium brown faint mottles
	B2	75-109	10 YR 5/3, b	nm	scl	1msbk	wsp	ds	Many fine and medium roots, common fine and medium brown faint mottles.
	C	109-150	10YR 5/3, r	m (7.5YR 4/4), b	sl	1msbk	wsp		Many macro pores,

Colour-b: brown, dgb: dark greyish brown, db: dark brown, dyb: dark yellowish brown, g: grey, gb: greyish brown, r: red, rg: reddish grey, vdb: very dark brown, Mottles–nm: no mottles, m: mottled, Structure–1: weak, 2: moderate, 3: strong, f: fine, m: medium, gr: granular, sbk: subangular blocky, Consistence– wnsp: wet, non-sticky, plastic, wsp, wet, sticky plastic, wssp: wet slightly sticky, plastic, wvsp: wet, very sticky, plastic, Boundary–c: clear, g: gradual, s: smooth, d: diffuse, w: wavy, Texture–sl: sandy loam, scl: sandy clay loam, l: loam, cl: clay loam, c: clay

Table 2: Morphology and classification of AK II soil mapping unit of Onwu river floodplain, Akraba-Itekpa, Yala Local Government area, cross river state

Profile No./Location	Horizon	Depth (cm)	Colour	Mottles	Texture	Structure	Consistence	Boundary	Remarks
AK II (Pedon 3): Fluaquentic humaquept, fine clayey siliceous isohyperthermic (USDA)/gleyic/vertic cambisol (FAO)									
06°43'59" N 008°37'55" E	Ap	0-26	10YR 2/2, vdb	-	sl	1fmsbk	wssp	cs	Many fine and medium roots, many macro and micro pores, mica flakes
Elevation 47 m	Bwg1	26-64	10YR 6/1, g	7.5YR 5/6	cl	1fmgr	wsp	cs	Common fine roots, many micro pores
	Bwg2	64-103	2.5YR 6/1, g	2.5YR 4/6	cl	1fmsbk	wvsp	gs	Few fine roots, many micro pores
	Cg	103-150	2.5YR 6/1, g	2.5 YR 4/6	gcl	1fmsbk	wvsp	-	Many micro pores
AK II (Pedon 4): Fluaquentic humaquept, fine clayey siliceous isohyperthermic (USDA)/gleyic/vertic cambisol (FAO)									
06°44'26" N 008°44'26" E	Ap	0-22	10YR 2/2, vdb	-	l	1fmgr	wssp	cs	Many fine, medium and coarse roots, many macro and micro pores, many ants, mica flakes
Elevation 48 m	ABw	22-54	10 YR 4/6, dyb	7.5YR 5/6	scl	1fmsbk	wvsp	gs	Common medium and coarse roots, many macro and micro pores
	Bwg	54-89	10 YR 4/2, dgb	7.5YR 4/4	cl	1fmsbk	wvsp	ds	Common fine roots
	Cg	89-130	2.5 YR 6/1, rg	7.5YR 5/8	cl	1mcsbk	wvsp		Few fine roots, many fine pores
AK II (Pedon 5): Fluaquentic humaquept, fine clayey siliceous isohyperthermic (USDA)/gleyic/vertic cambisol (FAO)									
06°44'10" N 008°37'38" E	Ap	0-20	10YR 2/1, b	2.5YR 4/6	sl	1fmgr	wssp	cs	Many fine roots, many ants, many macro and micro pores, few fine roots, mica flakes
Elevation 49 m	Bwg1	20-64	10 YR 5/2, gb	2.5YR 4/8	cl	1msbk	wsp	gc	Few fine roots, many fine mica flakes
	Bwg2	64-110	10 YR 5/1, g	2.5YR 4/8	c	1msbk	wvsp	ds	Few fine roots, many macro and micro pores
	Cg	110-150	7.5 YR 5/1, g	2.5YR 4/8	l	1msk	wvsp		Many micro pores

Colour-b: brown, dgb: dark greyish brown, db: dark brown, dyb: dark yellowish brown, g: grey, gb: greyish brown, r: red, rg: reddish grey, vdb: very dark brown, Mottles–nm: no mottles, m: mottled, Structure-1: weak, 2: moderate, 3: strong, f: fine, m: medium, gr: granular, sbk: subangular blocky, Consistence– wnsp: wet, non-sticky, plastic, wsp, wet, sticky plastic, wssp: wet slightly sticky, plastic, wvsp: wet, very sticky, plastic, Boundary–c: clear, g: gradual, s: smooth, d: diffuse, w: wavy, Texture–sl: sandy loam, scl: sandy clay loam, l: loam, cl: clay loam, c: clay red mottles in the subsurface of the profiles. Redoximorphic features associated with flooding/wetness resulted from alternating periods of reduction and oxidation of iron and manganese compounds in the soils (Stoops and Eswaran, 1985; Hossain *et al.*, 2011). The Akraba soil unit II (AK II) covers about 370 hectares and the soil supports the paddy rice during the rainy season.

Particle size distribution: Table 3 presents the results of particle size analysis of the soils. The texture of the soils varies from loamy sand or sandy loam in the surface over sandy clay loam, clay loam or clay in the subsurface soil. With the irregular distribution of clay fraction with depth,

Table 3: Physical characteristics of Onwu river floodplain for AK I and AKII soil units at Akraba-Itekpa, Yala Local Government area, Cross River state

	Particle size distribution			
Horizon depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural class
Pedon 1				
0-22	866.0	114.0	20.0	ls
22-65	586.0	114.0	300.0	scl
65-109	666.0	54.0	280.0	scl
109-152	626.0	74.0	300.0	scl
Pedon 2				
0.29	666.0	254.0	80.0	sl
29-75	466.0	294.0	240.0	l
75-109	586.0	194.0	220.0	scl
109-150	666.0	214.0	120.0	sl
Surface soil range	666.0-866.0	114.0-254.0	20.0-80.0	
Surface soil mean	76.6±4.99	18.4±3.5	50.0±1.5	ls
Subsurface soil range	466.0-666.0	54.0-294.0	120.0-300.0	
Subsurface soil mean	5.99±2.63	15.7±3.27	24.3±2.43	scl
Pedon 3				
0-26	586.0	314.0	100.0	sl
26-64	346.0	314.0	340.0	cl
64-103	326.0	314.0	360.0	cl
103-150	346.0	314.0	340.0	cl
Pedon 4				
0-22	606.0	314.0	80.0	l
22-54	466.0	294.0	240.0	scl
54-89	386.0	314.0	300.0	cl
89-150	326.0	314.0	360.0	cl
Pedon 5				
0-20	586.0	314.0	100.0	sl
20-64	406.0	214.0	380.0	cl
64-110	286.0	234.0	480.0	c
110-150	406.0	334.0	260.0	l
Surface soil range	588.0-606.0	314.0-314.0	80.0-100.0	
Surface soil mean	59.3±0.33	31.4±0.0	9.33±0.33	sl
Subsurface soil range	286.0-466.0	214.0-334.0	240.0-480.0	
Subsurface soil mean	36.6±1.58	29.4±1.19	34.0±2.04	cl

ls: Loamy sand, scl: Sandy clay loam, sl: Sandy loam, cl: clay loam, c: Clay , l: Loamy especially in Akraba soil unit II (AK II), the soils indicate the stratification associated with fluvial parent materials. In the Akraba soil unit I (AK I) (Pedons 1 and 2), there is an indication of clay eluviation-illuviation process that resulted in a distinct clay bulge within the argillic or kandic horizons (Akpan-Idiok and Ukwang, 2012). Silt content is considerably high in the Akraba soil unit II with mean values of 314.0±0.0 and 29.4±1.19 g kg^{-1} in the surface and subsurface for pedons 2, 3 and 5. Sand is the dominant fraction ranging from 466.0 to 866.0 g kg^{-1} in the Akraba soil unit I, while Akraba soil unit II (AK II) is rather low, ranging from 286.0 to 606.0 g kg^{-1} in sand content.

Chemical properties: The soils are strongly acid in reaction with mean surface values of 5.3 and 5.0 for Akraba soil units I and II, respectively (Table 4). Organic carbon content decreases with soil depth in all the pedons. It is rated moderate with surface mean values of 12.9 g kg^{-1} for AK I unit and high (37.0 g kg^{-1}) in the surface soil of AK II soil mapping unit. Total nitrogen has the same distribution pattern as organic carbon with surface soil mean values of 1.1 and 3.0 g kg^{-1} for AK I and AK II soil mapping units, respectively. Similar results were reported for floodplain soils of Okpauku river in Yala Local Government Area of Cross River State, Nigeria and Ganges river in Bangladesh (Akpan-Idiok, 2002; Hossain *et al*., 2011). Carbon-nitrogen ratios for the AK I and AK II soil mapping units are narrow as the values (12-16) are less than 25 (Paul and Clark, 1989) being the separating index for mineralization and immobilization of nitrogen in the soils. This narrow C:N ratio reflects high microbial activity and humification process for the release of nutrient elements for crop plants. This finding agrees with the data reported for the floodplain soils of Obubra in Cross River State (Akpan-Idiok, 2012).

Available phosphorous is low (1.37 to 12.50 mg kg^{-1}) in all the soils irrespective of their geomorphic units. The exchangeable Ca and Mg are rated low to moderate, while K and Na are rated low in the two soil mapping units. The Effective Cation Exchange Capacity (ECEC) is rated moderate (>4.0 cmol kg^{-1}) to high (10.00 cmol kg^{-1}) in the two soil units (Table 4). Earlier Researchers had the same observations for floodplain soils of Ganges river in Bangladesh, Niger Delta of Nigeria (Anand *et al*., 1977; Hossain *et al*., 2011; Egbuchua and Ojobor, 2011). The mean base saturation varies from 55.3 to 93.5% in the surface of AK I and AK II soil mapping units (Table 3); this range of values indicates the presence of soluble forms of basic cations in soil solution and that the applied fertilizers would be in available form for crop uptake in the soil.

Mineralogical characteristics

Quartz: Quartz is one of the most well-known minerals on earth. It is an important mineral in sand and silt fractions of soils. The x-ray powder diffraction analysis shows that quartz varied from 43.24 to 92.92% (Fig. 2, 3) in silt-clay fraction of surface and subsurface soils of AK I soil mapping unit. The percentage of quartz exceeds 87% in the surface and subsurface soils of the AK II soil mapping unit. The x-ray powder diffraction analysis characterized the mineral as follows: quartz (SiO_2) gives a diffused reflection pattern in the 21 to 58 2θ range, hexagonal grains having primitive unit cells with space grouping of P3221; lattice parameters of a = 4.91344, b = 4.91344 and c = 5.40524. The high percentage of quartz exceeding 90% confirms the quartz as an intrinsic component of sand-sized grains transported and deposited by flood water in the floodplain (Akpan-Idiok and Ukwang, 2012). The results are in agreement with the previous studies that obtained quartz and kaolinite in the silt fraction of soils in Southern Nigeria

Table 4: Chemical characteristics of Onwu river floodplain for AK I and AKII soil units at Akraba-Itekpa, Yala Local Government Area, Cross River State

Horizon depth (cm)	pH H_2O	Org. C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Avail. P ($mg\ kg^{-1}$)	Exchangeable bases ($cmol(+)(kg^{-1})$) Ca	Mg	K	Na	Exch. A. ($cmol\ kg^{-1}$)	ECEC ($cmol\ kg^{-1}$)	BS (%)
Pedon 1											
0-22	5.5	38.0	0.30	3.87	3.20	0.60	0.14	0.1	0.32	14.36	93
22-65	4.7	37.0	0.30	1.27	1.40	1.00	0.09	0.07	5.92	8.48	30
65-109	4.5	28.0	0.20	1.25	1.80	1.40	0.11	0.08	5.36	8.75	39
109-152	4.5	28.0	0.20	4	1.60	0.40	0.1	0.08	5.36	7.54	29
Pedon 2											
0.29	5.1	21.9	1.80	3.87	8.40	0.60	0.22	0.13	1.29	10.64	88
29-75	4.9	3.20	0.30	1.12	6.00	2.00	0.16	0.1	2.0	10.62	81
75-109	4.8	1.20	0.10	1.25	3.20	1.00	0.12	0.09	3.76	8.17	54
109-150	4.6	2.00	0.10	1.75	2.00	0.40	0.09	0.07	3.44	6.00	43
Surface soil range	5.1-5.5	3.80-21.9	0.30-1.80	3.87-3.87	3.2-8.4	0.6-0.6	0.14-0.22	0.10-0.13		10.64-14.36	88-93
Surface soil mean	5.3±0.15	12.9±5.0	0.11±0.04	3.87±00	5.8±1.3	0.6±0.0	0.18±0.02	0.12±0.01		12.5±0.93	93.5±1.25
Subsurface soil range	4.5-4.9	1.40-3.70	0.10-0.30	1.12-4.00	1.44-6.0	0.4-2.0	0.09-0.16	0.07-0.10		6.0-10.26	29-81
Subsurface soil mean	4.7± 0.05	26.0±0.30	0.20±0.30	1.77±0.39	2.67±0.62	1.03±0.22	0.11±0.01	0.08±0.004		8.2±0.49	46±6.9
Pedon 3											
0-26	5.0	25.9	2.10	5.00	3.40	1.00	0.21	0.12	7.36	12.09	39
26-64	4.7	3.60	0.30	2.62	1.00	1.20	0.09	0.08	6.24	8.61	28
64-103	4.6	1.60	0.10	1.75	1.20	1.60	0.08	0.06	9.44	12.38	24
103-150	4.7	1.40	0.10	2.50	1.40	1.20	0.09	0.06	5.76	8.51	22
Pedon 4											
0-22	5.1	45.9	3.70	3.25	4.20	2.60	0.22	0.13	0.96	8.11	88
22-54	4.7	15.2	1.30	1.75	3.80	1.80	0.18	0.12	2.4	8.3	71
54-89	4.6	7.40	0.60	3.25	4.40	2.20	0.17	0.12	1.28	8.17	84
89-150	4.6	2.60	0.20	2.25	3.60	3.80	0.14	0.10	6.4	14.04	54
Pedon 5											
0-20	5.0	3.91	3.30	5.25	1.80	0.60	0.19	0.12	5.44	8.15	33
20-64	4.8	7.20	0.60	5.37	1.80	1.40	0.2	0.13	11.84	15.37	23
64-110	4.7	5.0	0.40	12.5	1.80	0.40	0.15	0.10	16.74	19.17	13
110-150	4.7	3.80	0.10	1.37	2.00	0.80	0.11	0.08	8.72	11.71	25
Surface soil range	5.0 - 5.1	25.9-45.9	2.10-3.70	3.25 - 5.25	1.8-4.2	0.6-2.6	0.19-0.22	0.12-0.13	0.32-1.29	8.11-12.09	33-88
Surface soil mean	5.0±0.19	37.0±2.90	30.0±0.20	4.5±0.32	3.1±0.35	1.4±0.31	0.21±0.002	0.12±0.002	1.61±0.24	9.5±0.66	55.3±8.71
Subsurface soil range	5.6 - 4.7	1.40-15.2	0.10-1.30	1.37-12.50	1.0-4.4	0.4-3.8	0.08-0.21	0.06-0.13	2.0-5.92	8.17-19.17	13-84
Subsurface soil mean	4.7±0.03	5.30±1.20	0.40±0.10	3.7±1.01	2.3±0.4	1.6±0.28	0.13±0.013	0.09±0.008	4.30±0.45	11.81±1.1	38.22±7.24

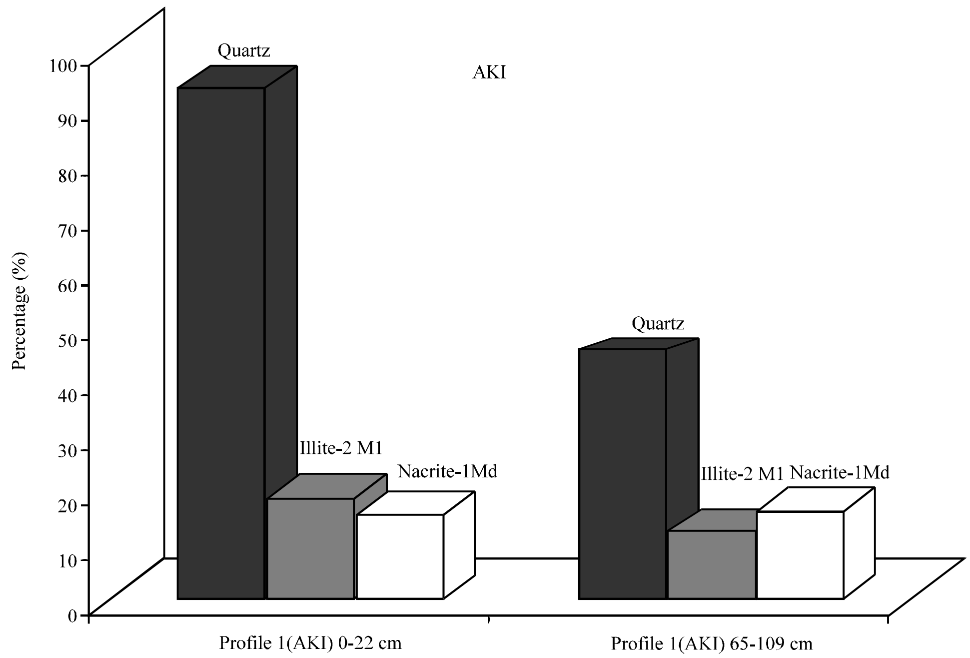


Fig. 2: Distribution of minerals in silt-clay fraction of AK I soil mapping units, Akraba, Yala, Cross River State, Nigrtia

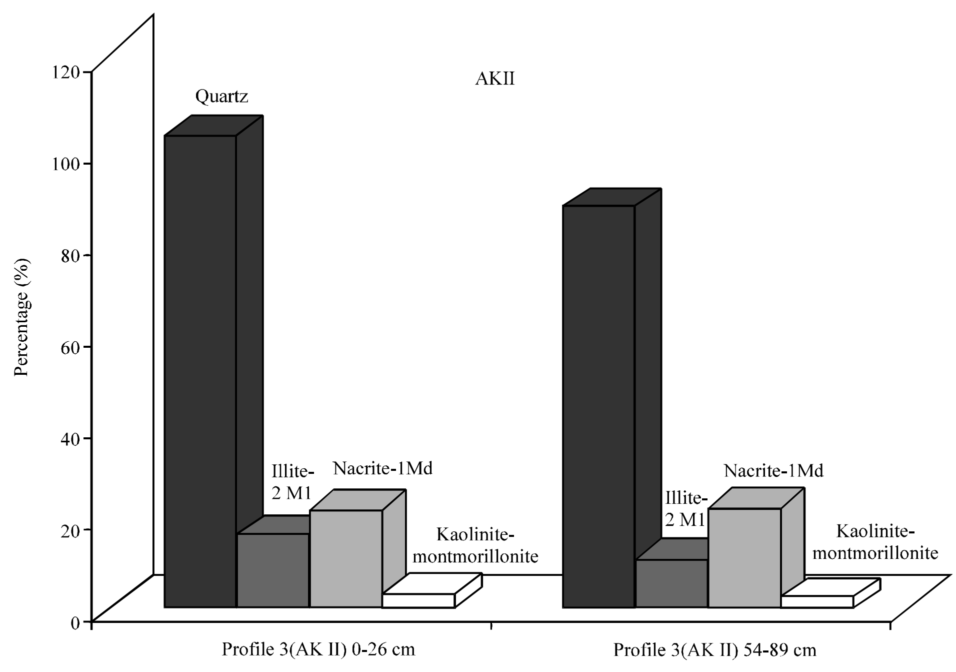
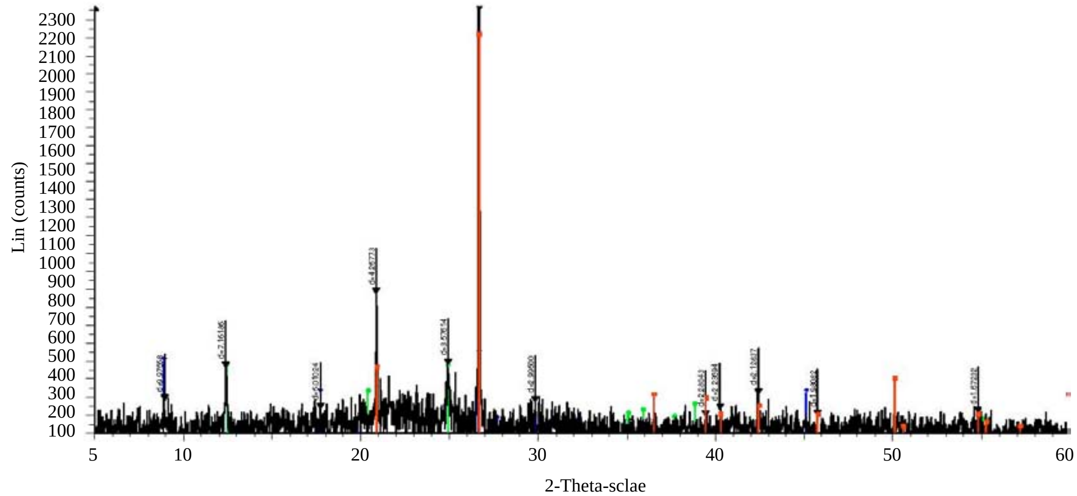


Fig. 3: Distribution of minerals in silt-clay fraction of AK II soil mapping units, Akraba, Yala, Cross River State, Nigrtia

(Jungerius and Levelt, 1964; Juo, 1981; Chikezie *et al*., 2010). Quartz is an agricultural limitation in terms of fertility but its association with other soil elements ensures structural development, water permeability, biomass productivity, aeration and being a component of soil medium that



File: 3-1. Raw-type: 2Th\Th looked-start 5.000 °-End: 59.966 °Step: 0.021 °Step time: 89. #-Temp: 25°C (Room)-Time started: 12#-2-Theta: 5.000 °-Theta: 2.500°-Chi: 0.000°-Phi: 0.00 °-X: 13.0 mm operations: background 5.623, 1.000|import

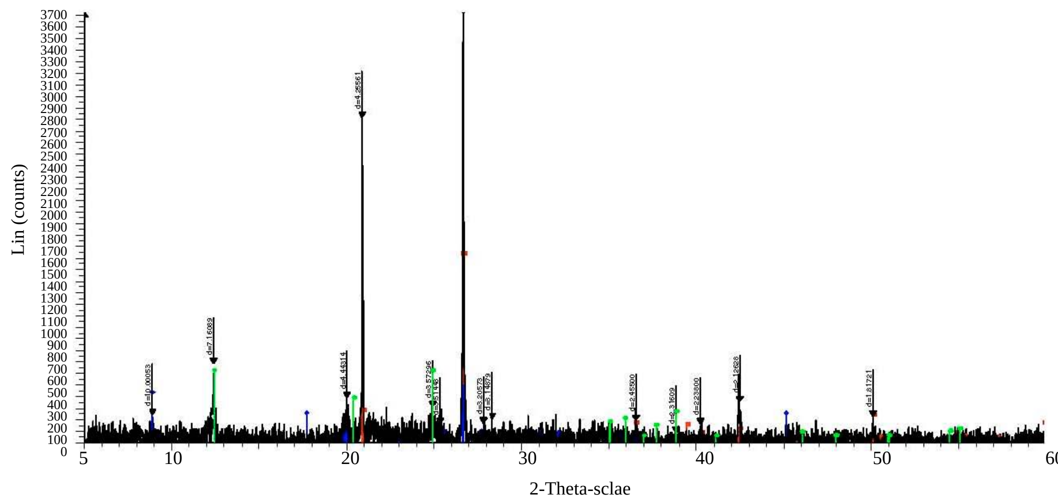
00-046-1045 (°)-Quartz, syn-Sio2-Y: 87.77%-dx by: 1.-WL: 1.5406-Hexagonal-a 4.91344-b 4.9134405.40524-alpha 90.000-gamma 120.000-primjitive-P3221 (154)-3-113.010-1/10 PDF 3.4-S-Q

00-026-0911 (l)-Illite-2M1 (NR)-(K.H3O) A12Si3AIO10(OH)2-Y: 16.11%-dx by: 1.-WL: 1.5406-Monoolinic-a 5.16000-b9-00000-c20.16000-alpha 90.000-gamma 90.0000-Base-centered-O2/o (15)-4-9

00-029-1488 (N)-Naorite-1Md-a12Si2O5(OH)4-Y: 21.48%-dx by: 1.-WL: 1.5406-Monoolinic-a5.16000-b8.93000-c 7.39000-alpha 90.000-gamma 90.000-Base-centered -O°(0) –2-329.676-Vlo PD

00-029-1490 (Q)-Kaolimite-ontrnorillonite- Na0.3A14SiSO15(OH) 6.4H2O-Y: 2.61%-dx by: 1.-WL: 1.5406-1/lo PDF1.-S-Q 4.3%

Fig. 4: X-ray diffractograms of silt-clay fraction at depth 0-22 cm (AK I) soil mapping unit of Onwu river floodplan in Yala Cross River State Nigeria



File: 4-1. Raw-type: 2Th\Th looked-start 5.000 °-End: 59.966 °Step: 0.021 °Step time: 89. #-Temp: 25°C (Room)-Time started: 12#-2-Theta: 5.000 °-Theta: 2.500°-Chi: 0.000°-Phi: 0.00 °-X: 13.0 mm operations: background 5.623, 1.000|import

00-046-1045 (°)-Quartz, syn-Sio2-Y: 87.77%-dx by: 1.-WL: 1.5406-Hexagonal-a 4.91344-b 4.9134405.40524-alpha 90.000-gamma 120.000-primjitive-P3221 (154)-3-113.010-1/10 PDF 3.4-S-Q

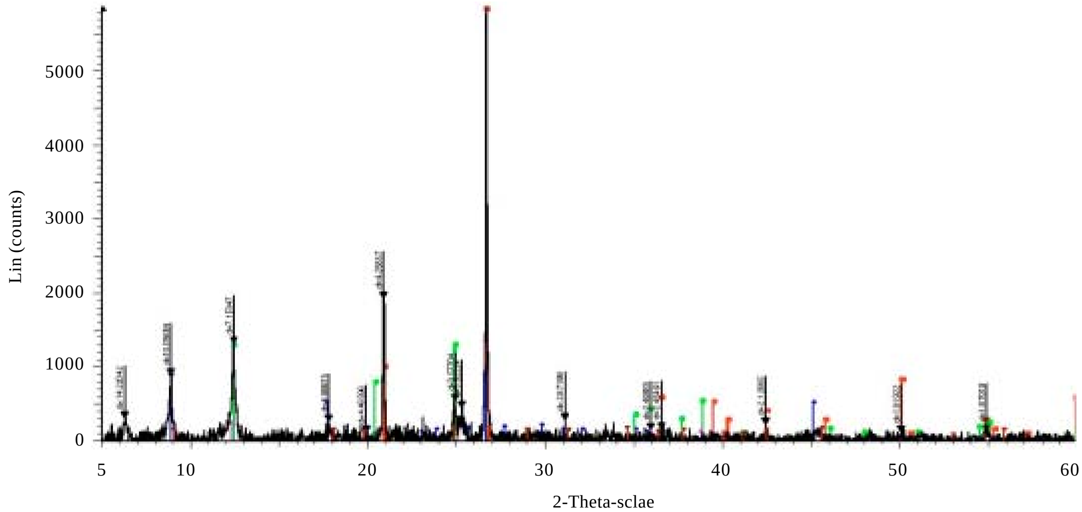
00-026-0911 (l)-Illite-2M1 (NR)-(K.H3O) A12Si3AIO10(OH)2-Y: 16.11%-dx by: 1.-WL: 1.5406-Monoolinic-a 5.16000-b9-00000-c20.16000-alpha 90.000-gamma 90.0000-Base-centered-O2/o (15)-4-9

00-029-1488 (N)-Naorite-1Md-a12Si2O5(OH)4-Y: 21.48%-dx by: 1.-WL: 1.5406-Monoolinic-a5.16000-b8.93000-c 7.39000-alpha 90.000-gamma 90.000-Base-centered -O°(0) –2-329.676-Vlo PD

00-029-1490 (Q)-Kaolimite-ontrnorillonite- Na0.3A14SiSO15(OH) 6.4H2O-Y: 2.61%-dx by: 1.-WL: 1.5406-1/lo PDF1.-S-Q 4.3%

Fig. 5: X-ray diffractograms of silt-clay fraction at depth 65-109 cm (AK I) soil mapping unit of Onwu river floodplan in Yala Cross River State Nigeria

provides nutrients for plant uptake (Devnita, 2009; Chikezie *et al*., 2010). The x-ray diffractograms of the mineral are shown in Fig. 4-7.



File: 1-3. Raw-type: 2Th\Th looked-start 5.000 °-End: 59.966 °Step: 0.021 °Step time: 89. #-Temp: 25°C (Room)-Time started: 11#-2-Theta: 5.000 °-Theta: 2.500°-Chi: 0.000°-Phi: 0.00 °-X: 13.0 mm operations: background 5.623, 1.000|import

00-046-1045 (°)-Quartz, syn-Sio2-Y: 102.80%-dx by: 1.-WL: 1.5406-Hexagonal-a 4.91344-b 4.9134405.40524-alpha 90.000-gamma 120.000-primjitive-P3221 (154)-3-113.010-1/10 PDF 3.4-S-Q

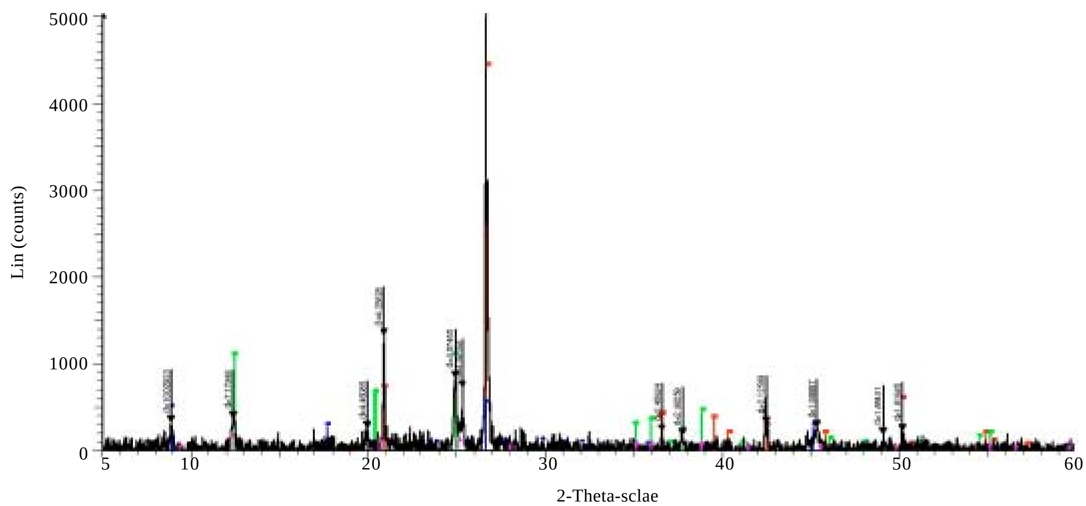
00-026-0911 (l)-Illite-2M1 (NR)-(K.H3O) A12Si3AIO10(OH)2-Y: 16.11%-dx by: 1.-WL: 1.5406-Monoolinic-a 5.19000-b9.00000-o20.16000-alpha 90.000-gamma 90.0000-Base-centered-O2/o (15)-4-9

00-029-1488 (N)-Naorite-1Md-a12Si2O5(OH)4-Y: 21.32%-dx by: 1.-WL: 1.5406-Monoolinic-a5.16000-b8.93000-c 7.39000-alpha 90.000-gamma 90.000-Base-centered -O°(0) –2-329.676-Vlo PD

00-029-1490 (Q)-Kaolimite-,ontrnorillonite- Na0.3A14SiSO15(OH) 6.4H2O-Y: 3.23%-dx by: 1.-WL: 1.5406-1/lo PDF1.-S-Q 4.4%

00-0.31-0.968 (D) –Illite-1M-KA12(Si3A1)O10(OH) 2-Y: 2.19%-dx by: 1.-WL: 1.5406-Monoolinic-a5.2000-b9.00000-c10.01000-alpha90.000-gamma90.000-base-centered-O2/m (12)-2-461.351-1/lo

Fig. 6: X-ray diffractograms of silt-clay fraction at depth 0-22 cm (AK II) soil mapping unit of Onwu river floodplan in Yala Cross River State Nigeria



File: 2-1. Raw-type: 2Th\Th looked-start 5.000 °-End: 59.966 °Step: 0.021 °Step time: 89. #-Temp: 25°C (Room)-Time started: 12#-2-Theta: 5.000 °-Theta: 2.500°-Chi: 0.000°-Phi: 0.00 °-X: 13.0 mm operations: background 5.623, 1.000|import

00-046-1045 (°)-Quartz, syn-Sio2-Y: 87.77%-dx by: 1.-WL: 1.5406-Hexagonal-a 4.91344-b 4.9134405.40524-alpha 90.000-gamma 120.000-primjitive-P3221 (154)-3-113.010-1/10 PDF 3.4-S-Q

00-026-0911 (l)-Illite-2M1 (NR)-(K.H3O) A12Si3AIO10(OH)2-Y: 16.11%-dx by: 1.-WL: 1.5406-Monoolinic-a 5.16000-b9-00000-c20.16000-alpha 90.000-gamma 90.0000-Base-centered-O2/o (15)-4-9

00-029-1488 (N)-Naorite-1Md-a12Si2O5(OH)4-Y: 21.48%-dx by: 1.-WL: 1.5406-Monoolinic-a5.16000-b8.93000-c 7.39000-alpha 90.000-gamma 90.000-Base-centered -O°(0) –2-329.676-Vlo PD

00-029-1490 (Q)-Kaolimite-ontrnorillonite- Na0.3A14SiSO15(OH) 6.4H2O-Y: 2.61%-dx by: 1.-WL: 1.5406-1/lo PDF1.-S-Q 4.3%

Fig. 7: X-ray diffractograms of silt-clay fraction at depth 54-89 cm (AK II) soil mapping unit of Onwu river floodplan in Yala Cross River State Nigeria

Illite: Illite is 2:1 type of non-swelling (mica type) mineral occurring in pedogenic and sedimentary environment and is believed to be inherited largely from parent rocks. It has a basal spacing of 1.0 mm, with K^+ fixed in the interlayer charge of -0.80 to -0.82 per formular weight (Hower and Mowatt, 1966; Gaudette *et al.*, 1964; Garrels, 1984; Hassannezhad *et al.*, 2008). The x-ray diffraction powder pattern shows a diffused prism reflection in 9 to 50% 2θ range for AK I soil samples (Fig. 2 and 3). The x-ray powder diffracterized the mineral as follows 2M1 polymorphic type with a chemical formular $(K_1(H_2O)Al_2S_i3Al_{10}(OH)_2)$, monoclinic grains with cell parameters, a = 5.19000, b = 9.00000 and c = 20.16000, base centred crystal with space grouping C2/C (15), α = y = 90° in AK I and AK II soil mapping units. The characteristics of the polymorph, 1 M with the formular, $KAl_2\ (S_i3Al)O_{10}(OH)_2$ were as follows: monoclinic but with slight variation in lattice parameters, a = 5.20000, b = 9.00000 and c = 10.01000 and base-centred with space grouping C2/m (12) α = y = 90° in the AK II soil mapping unit (Fig. 3a-d).

Illite concentration in the floodplain soils is rated low (<20%) probably because of transformation to the other 2:1 clay minerals and the poor drainage conditions of the soils that favours leaching and release of K from the mineral. Similar low percentage values were obtained for paddy soils of Mazandaran province in Northern Iran (Hassannezhad *et al.*, 2008). Figure 4-7 present the x-ray diffractograms of the mineral.

Nacrite: Nacrite is the rarest polymorph of the kaolin-group minerals. Nacrite with the formular, $(Al_2Si_2O_5(OH)_4)$ constituted 15 and 21% in AK I and AK II soil mapping units, respectively (Fig. 2 and 3). The x-ray diffraction powder pattern in the 17 to 48 2θ range for AK I soil mapping unit and from 16 to 55 for AK II soil mapping unit (Fig. 2 and 3). The x-ray powder analysis revealed also the characteristics of mineral as follows: monoclinic grains with base-centred C^x1^x (o) lattice, unit cell parameters of a = 5.16000, b = 8.93000, c = 7.39000 ∝ = 90°, while y = 90°. Nacrite is an indicator of concentration pore solutions and the order of formation of this kaolin polymorph does not depend on soil pH and temperature, but rather on the concentration of the initial pore solution (Gorlich, 1957). The presence of nacrite in the seasonally flooded soils of Akraba-Itekpa agrees with previous findings that nacrite could be formed authigenically within a few weeks at ambient temperature by precipitation from pore solutions, as a result of evaporation (Lippmann, 1982; Buhmann, 1988). This finding contrasts the earlier perception that nacrite is a product of a high temperature genetic environment. Precipitation from saturated pore solution has been reported as the mechanism of formation of kaolinite-mineral polymorph-nacrite (Lippmann, 1982; Buhmann, 1988; Al-Farraj, 2008; Hassannezhad *et al.*, 2008). The x-ray diffractograms of the mineral are presented in Fig. 4-7.

Kaolinite-montmorillonite: A mixed layer structure of kaolinite-montmorillonite was detected by x-ray powder diffraction in soil samples of AK II soil mapping unit (Fig. 2 and 3). Montmorillonite is the main clay mineral in soils under poorly drained conditions with low watertable depth (Abtahi and Khormali, 2001; Hassannezhad *et al.*, 2008). The kaolinite-montmorillonite with the formular, $(Na_{0.3}Al_{1.4}Si_6O_{15}(OH)H_2O)$ varied from 2.61 to 3.23% in the soils of AK II mapping unit (Fig. 2 and 3). The association of the two discrete mineral species was bonded by sesquioxides with percentage variation values of 4.3 to 4.4% in the soils. The presence of kaolinite-montmorillonite in the silt-clay fraction of the soils must have been favoured by the following environmental factors: low-lying relief, poor drainage, presence of considerable amounts of illite clay mineral, considerable amounts of basic cations, cracking clay materials as observed in the field. When illite is exposed to weathering, K released from layers favours formation of Montmorillonite and Kaolinite (Hassannezhad *et al.*, 2008). The identification of the kaolinite-montmorillonite interlayered materials is consistent with earlier works that detected intergrade minerals in poorly drained low lying topographic landscape (Garrels, 1984; Hassannezhad *et al.*, 2008; Chikezie *et al.*, 2010; Hossain *et al.*, 2011).

The identified clay minerals have important implications for agricultural and environmental purposes because of adsorption, fixation and release of elements in the soils. The clay minerals are similar, indicating that the soils of AK I and AK II mapping units are derived from the same parent materials and that the humid tropical climatic conditions that occurred in the area support intense pedogenic processes in AK I soil mapping unit. Also, the considerable amounts of illite must have undergone alteration under poorly drained conditions to form intergrade materials of kaolinite-montmorillonite in AK II soil mapping unit. Figure 4-7 present the x-ray diffractograms of the mineral.

Taxonomic classification: The soils were classified according to the USDA keys to Soil Survey Staff (2010). Akraba soil unit I (AK I) classifies as Typic Kandiudults, Coarse loamy siliceous, Isohyperthermic because of low base status, kandic horizon, udic moisture regime, sandy nature between 50 and 100 m in depth of the profile. According to the criteria for (FAO, 2006), the Akraba soil unit I (AK I) has been classified as Haplic Acrisols.

Akraba soil unit II (AK II) classifies as Flaquentic Humaquepts, fine clayey, mixed, isohyperthermic because of the presence of umbric epipedon and cambic horizon with dominant moist colour value of 4 or more, chroma of 1 or 2, with minimal horizon development. Other characteristics include aquic conditions with black to grey matrix with coarse prominent red mottles (2.5 YR 4/6, 2.5 YR 4/8), saturated with water for more than 30 days in the rainy season, irregular decrease of organic carbon below 0.20% within 125 cm depth. In the FAO (2006) system, the soils are classified as Gleyic/Vertic cambisols.

CONCLUSION

The study highlights the morphological, physical, chemical and mineralogical properties of Onwu river floodplain in Yala Local Government Area of Cross River State, Nigeria. The soils are formed from recent alluvial-collovial materials and are well-drained for AK I and poorly drained for AK II units. The soils are also characterized by very strong acidity in reaction, low available P and moderate to high organic carbon, Effective Cation Exchange Capacity (ECEC). The common minerals in the soils include quartz, illite, nacrite and kaolinite-montmorillonite. Under intensive cultivation, the soils require appropriate management practices such as drainage, application of lime and fertilizers as well as other conservation measures.

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