MORPHOLOGY, CHARACTERISATION AND CLASSIFICATION OF NUN RIVER PLAIN SOILS IN BAYELSA STATE, NIGERIA

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ABSTRACT: *With the mounting pressure on available land for agriculture due to industrialization, increased population and climate change, rational use of available land is inevitable. This cannot be achieved without adequate and current information and knowledge on the characteristics of the soils. Hence, the morphological, physical and chemical characteristics of the Nun River plain soils of Bayelsa State were studied. Nine profile pits were dug on various landscape positions (levee crest, middle slope and lower slope) in Odi, (ODI) Koroama (KRM) and Niger Delta University teaching and research farm (NDU), making three pits in each location. The soils were dominated by silt-sized particles, weakly structured in the upper layers and consistence also friable to slightly firm. pH was moderately to slightly acid, ranging from 5.64 to 6.30, available P (mg/Kg) from 0.6 to 22 and organic C from 0.11 to 5.26%, exchangeable bases, except K and CEC were low. The soils are classified according to United States Department of Agriculture (Soil Survey Staff, 2014) and Food and Agriculture Organisation and (FAO/ISRIC, 2014) as Inceptisol and Cambisol, having udic moisture regime and iso hyperthermic temperature regime. Only ochric epipedon and cambic B horizon are encountered as diagnostic horizons. The ODI1soils was classified as Humic Dystrudepts (Fluvic Cambisol), ODI2 soils, KRM2, NDU2 and NDU3 into Aquic Dystrudepts (Fluvic Cambisol), ODI3 Aeric Epiaquepts (Fluvic Cambisol), KRM1, Udic Dystropepts (Humic-fluvic Cambisol), KRM3, Typic Epiaquepts (Fluvic Cambisol), and NDU1, Udic Dystropepts (Fluvic Cambisol).*

KEYWORDS: morphology, characterization, classification, floodplain, Nun River

INTRODUCTION

Owing to industrialization, increased population and pressure on available land space, soils of the levee crest, levee slope and lower slope of the Nun River floodplain soils in Bayelsa State are intensively cultivated. With the climate change which comes with extreme flooding, even the levee crest which was formerly not flooded is now flooded annually. Dickson et al. (2019) reported that information and knowledge on the characteristics, capabilities and suitability of these soils are not current, inadequate and obsolete. One sure way of generating information on these soils is their characterization and classification. According to Tufa et al. (2021), Characterization and classification of soil is the main central information source for judicious soil management and enhance agricultural economy. Soils differ in properties due to differences in morphological, physical, chemical and mineralogical properties (Ukut et al., 2014). According to Osujieke et al.

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(2018), soil characterization deals with the separation of soils into groups of similar properties such as colour texture, consistence, etc. for morphology, sand, silt, clay, bulk density, porosity for physical and pH, organic matter, total nitrogen, available phosphorus and exchangeable cations, etc. for chemical properties. Characterization of morphological, physical and chemical properties helps in delineation and management of soils and their properties (Senjobi et al., 2019). Soil characterization provides the basic information necessary to create functional soil classification schemes, and assess soil fertility in order to unravel unique soil problems in any ecosystem (Lekwa et al., 2004).

On the other hand, soil classification organizes knowledge, facilitates transfer of experience and technology from one place to another and compares soil properties [7] (Sharu et al., 2013). The basic goal of soil classification is to organize knowledge so that the soil properties are remembered and their relationships understood more easily for specific objectives [8, 9] (Esu, 2010; Zata et al., 2013). Soil classification like any other system of classifying objects, ideas or concepts provides a framework for the storage and retrieval of soil information. It also gives room for the retention of useful soil information collected in the past for the acquisition of new ones. When soil classification is properly carried out, it can help organize knowledge of extremely complex landscape features into units that can be readily understood and manipulated by man (Esu, 2010). Ukut et al. (2014), emphasized that soil characterization and classification contribute to the alleviation of the adverse effect of soil diversity and aid precision agriculture [3]. This study was carried out to obtain detail characterization of the morphological, physical and chemical characteristics of the Nun River plain soils, to give a taxonomic classification of the soils using Soil Survey Staff (2014) and FAO/ISIRIC (2014) systems.

MATERIALS AND METHODS

Description of the Study Areas

This study was carried out in Bayelsa State in the Niger Delta region, Southern Nigeria. The study locations lie between latitude 05° 22' 03.9" N and 04° 59' 08.9" N and longitude 006° 30' 21.1" E and 006° 06' 54.1" E. As the Niger River flows southward and breaks up into two- the Forcados and Nun Rivers in Bayelsa State, the Nun River, runs north and south down the middle of the Bayelsa State, which remains the most direct tributary of the Niger. The Odi community lie by the Nun River on the western bank, Koroama community, by Taylor Creek that receives waters from the Nun River and Niger Delta University (Amassoma) by the Nun River down south towards the Atlantic Ocean (Figure 1) were chosen for the study due to the proposed agricultural intensification by the state. The annual rainfall is 2000-4500mm, spread over 8 to 10 months of the year and bimodal, peaking at June and September. The relative humidity averages 80% all over the state and temperature is fairly constant with a maximum of 30ºC. The natural vegetation is tropical rainforest. Food is cultivated on the levee crest, levee slope, backslope and on recent alluvial soils on channels of present active rivers. The levee crest soils are no longer flooded while most flood plain soils and alluvial soils in the channels of present active rivers are flooded yearly by the Niger

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River floods according to Dickson et al. (2021) but most levee crest soils are also flooded in recent years due to climate change.

Field Study and Soil Analyses

Three different locations, Odi, Koroama and Niger Delta University Wilberforce Island were selected and mapped out for this study. Surface (0-15cm) and (15-30cm) soil samples were collected at 100 m intervals on the land types encountered (viz. upper slope or levee crest, middle slope or levee slope and lower slope or floodplain) using soil auger which also served as mapping units. The soil mapping units (SMUs) designations were ODI1, ODI 2 and ODI3 for Odi, KRM1, KRM2, and KRM3 for Koroama soils and NDU1, NDU2 and NDU3 for Niger Delta University Teaching and Research farm, co-ordinates of the soil mapping units were taken

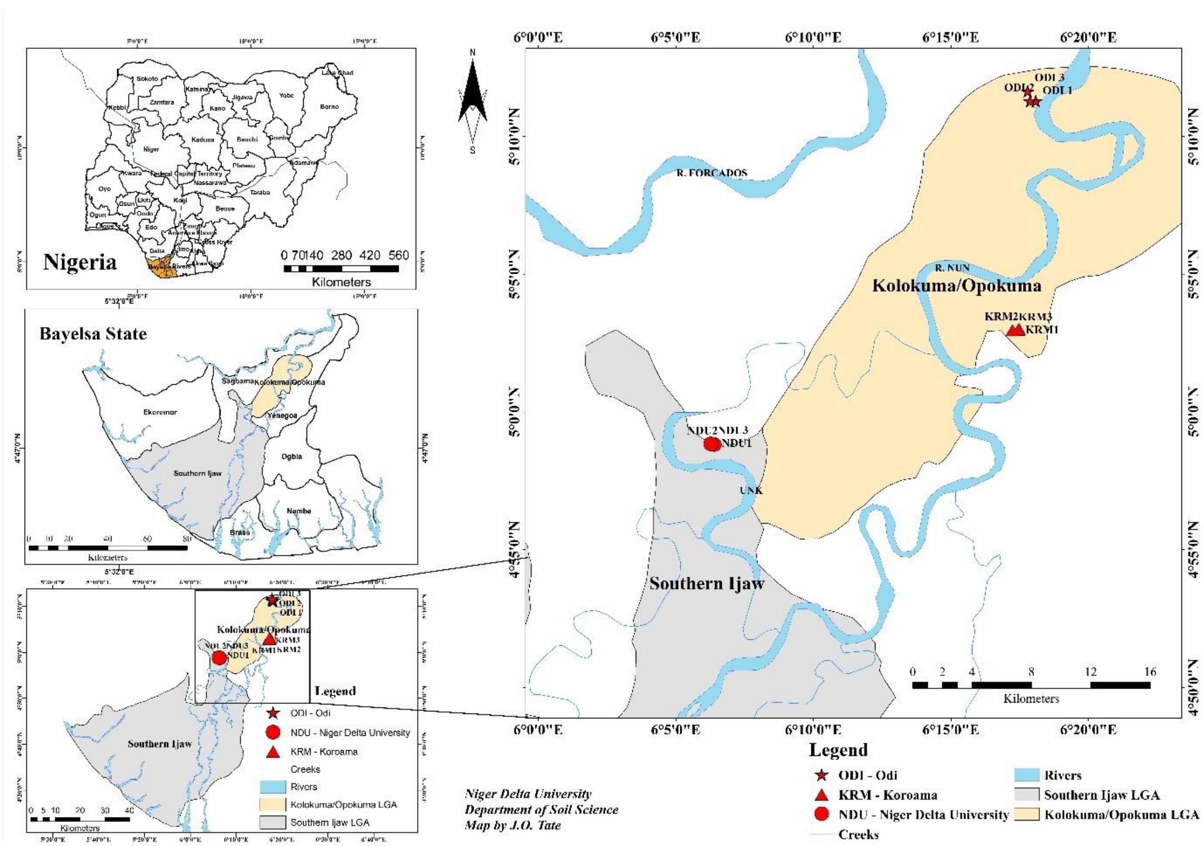

Figure 1: Map of Bayelsa State showing the sampling locations

and the land area occupied which are presented in table 1. Representative profile pits (2x1.5x2 m) were dug on each mapping unit, making a total of three pits per location. General site description including climate, vegetation, and land use, gradient of slope, drainage, soil surface form and the degree of erosion were recorded. Soil sampling procedures followed the methods as prescribed by

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the USDA Soil Taxonomy and the World Resource Base. Soil profiles were morphologically described in-situ and samples collected from the different pedogenetic horizons for physico-chemical properties following standard procedures and processed in the laboratory after air drying at room temperature.

Soil samples collected were air-dried, crushed and sieved to pass through a 2 mm mesh and analyzed in the Green River Project laboratory of the Nigerian Agip Oil Company and Zadell laboratory, Port Harcourt, Nigeria. Standard laboratory procedures were used to determine the physical and chemical properties of the soil samples as reported by Dickson et al (2021).

[1] **Table 1: Soil Maping Unit, Profile Pit Location and Land Area**

Study Location	Soil Mapng Unit	Geo-reference of Profile Pit	No. of Profile Pit	Land Area (Hectares)	Land Area (%)
Odi	ODI1	N 05˚ 11' 17.4" E 006˚ 18' 04.6"	1	142.485670	11.7
	ODI2	N 05˚ 11' 17.1", E006˚ 17' 52.3"	1	65.061343	5.3
	ODI3	N 05˚ 11' 38.7”" E 006˚ 17' 47.0"	1	138.649761	11.4
Koroama	KRM1	N 05˚ 02' 59.9", E 006˚ 17' 28.8"	1	13.182619	1.1
	KRM2	N 05˚ 02' 59.2",E 006˚ 17' 26.9"	1	10.647992	0.9
	KRM3	N 05˚ 02' 58.1", E 006˚ 17' 14.0"	1	21.428567	1.8
Niger Delta University	NDU1	N 04˚ 58' 49.1" E 006˚ 06' 23.7"	1	24.048062	2.0
	NDU2	N 04˚ 58' 49.9", E 006˚ 06' 17.5"	1	7.533081	0.6
	NDU3	N 04˚ 58' 50.5", E 006˚ 06' 15.7"	1	60.527688	5.0

RESULTS AND DISCUSSIONS

Morphological Characteristics

The morphological characteristics of Nun River floodplain soils are summarized in Table 2, 3 and 4. All the soils investigated were very deep as all the horizon depths were 190 cm and above. For the ODI location, ODI1 soils was located on the levee crest, ODI2 on the levee slope while ODI3, on the lower slope. The same applied to KRM1, KRM2 and KRM3 for the location and NDU1, NDU2 and NDU3 for the Niger Delta University Teaching and Research farm location. Many roots were observed in the upper layers of the profiles depicting the rain forest vegetation. Little wonder erosion effect was very limited in the study sites. Soil boundaries were wavy or clear smooth reflecting depositional history. Mica flakes were many to common which indicated the presence of weatherable minerals and that the pedons were embryonic in nature. The occurrence of black concretions in the bottom layer of ODI2, many dark concretions in the seventh and eighth layers of ODI3 and the occurrence of black concretions in the bottom layer of ODI2, many dark concretions in the seventh and eighth layers of ODI3 and iron concretions in KRM1 suggested previous anthropogenic influence.

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Generally, the soils were weakly structured as they had crumbly to weak subangular blocky structures especially in the upper layers of the profiles. Similarly, the soil consistence was friable or slightly firm especially in the upper layers and non-sticky, non-plastic to slightly sticky and slightly plastic, also in the upper layers. One may therefore, understand the high level of river bank erosion in the study area as the soils are bombarded with waves from rivercrafts.

All the soils were dominated by 10 YR Hues followed by 7.5 YR in ODI2 and ODI3. Soil colours at the surface layers were darker than the deeper layers. Soil colour of ODI1, in the surface layer (moist) was dark brown (10 YR 3/3) while subsurface soil colour was dark yellowish brown (10 YR 4/4). The KRM1 surface layer soil colour (moist) was dark yellowish brown (10 YR ¾) while subsurface layer colours varied from brown (10 YR 4/3) through very dark grayish brown (10 YR 3/2), dark grayish brown (10 YR 4/2) to brown (10 YR 4/3) down the profile. Also, surface layer colour (moist) of NDU1 was dark brown (10 YR 3/3) while the subsurface soil colours varied from dark yellowish brown (10 YR 4/4) through yellowish brown (10 YR 5/4), brown (10 YR 5/3) to light brownish gray (10 YR 6/2) with many, coarse, distinct, reddish brown (5 YR 4/4) mottles and many, coarse, prominent, reddish brown (5 YR 4/4) mottles occurring on the two bottom layers of the soil profile. As one move from the levee crest through levee slope to the lower slope, hydromorphic influence increases, moving to close to the soil surface. For instance, the three lowest soil layers of ODI1 were subject to hydromorphic influence with common, medium, distinct, dark brown mottles (7.5 YR ¾), medium, coarse, distinct, dark reddishbrown mottles (2.5 YR ¾) and medium, coarse, prominent, reddish brown (5 YR 4/4) mottles but hydromorphic influence was observed from the second layer of ODI3, KRM3 and NDU3 (Table 2, 3 and 4). According to Akpan-Idiok and Ogbaji (2013) for Cross Rivers State floodplain soils in Nigeria, the alternate wetting and drying of the soils led to reduction and subsequent release of iron oxides, accumulating in the form of strong brown, brown and red mottles on the subsurface layers of the profiles. Lawal et al (2013) suggested grayish coloration indicated that the affected horizon has been under hydromorphic influence for a longer time each year. By implication, the alternate wetting and drying processes led to reduction and release of iron oxides resulting in the accumulation of light reddish brown, reddish brown and dark reddishbrown mottles on the surfaces of the affected layers. Gleying (chroma of 2 or less) was observed in the two bottom layers of the ODI2 profile which indicated longer period of submergence by water. At the time of sampling which was in February, 2015 (dry season), the ODI2 soil profile was completely dry indicating that ground water influence occurred in the rainy season which accompanied the annual floods, leading to rise in ground water table. The soils are flooded by the annual seasonal floods in most years which accompanied the rainy season. Even in years when the annual flood did not cover the entire land, a greater proportion of the soil was under groundwater influence due to rise in water table, creating room for alternate wetting and drying. The alternate wetting and drying process leads to reduction and release of iron oxides resulting in the accumulation of reddish brown, yellowish brown, and yellowish red mottles in the respective layers for ODI3. The dark coloration of the top soil layers of ODI1 and ODI2 soils was attributed to organic matter accumulation. Darkened surface layer of ODI3 indicated humification by organic materials [16] (Abate et al.

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2014), as the soils have been fallowed for some years. The presence of medium to coarse continuous pores in the ODI2 profile implied soils have been fallowed for some years. The presence of medium to coarse continuous pores in the ODI2 profile implied that the natural drainage of the profile was good enough to drain water during the dry season and the cause of hydromorphic influence is groundwater from the rains and natural flood. However, owing to rise and drop in water table in the profile, a lot of the fine pores at two the bottom layers were blocked, hence the two layers had chroma of 2 or less indicating longer period of submergence and gleitization as a soil forming process had set in. Medium to coarse continuous pores occurred also in the ODI3 profile and the profile was dry at the time of sampling with water table below the profile. Weak structure in the surface 40 to 60 cm of Odi soils was attributed to cultivation which weakened peds and such peds easily disaggregate. Again, variation in stickiness and plasticity

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Table 2: Morphological Characteristics of Odi Soils

Horiz	Depth cm	Soil Colour	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			clour	pattern			Moist	Wet				
ODI1												
Ap	0 – 26	10 YR 3/3			Fine silt loam	Cr	Fr	Ss sp	Many fine medium	-	Clear smooth	Many
A	26 – 60	10 YR 4/4			Silt loam to loam	WSAB	Fr	Ss sp	Common medium	-	Clear wavy	Many
B1	60 – 78	10 YR 4/4			Silt loam to loam	SAB	Mf	Ms mp	Common medium	-	Clear wavy	Many
B2	78 – 120	10 YR 4/4			Silt loam	SAB	Sf	Ss sp	Few medium	-	Clear wavy	Many
B3	120 – 135	10 YR 4/4			Loam	SAB	Sf	Ss sp	Few medium	-	Clear wavy	Many
C1	135 – 163	10 YR 4/4	7.5 YR 3/4	C2D	Silty clay loam	SAB	Mf	Ms mp		-	Clear wavy	Many
C2	163 – 186	10 YR 4/4	2.5 YR 3/4	M3D	Silt loam	SAB	Mf	Ms mp		-	Clear wavy	Many
C3	186 – 200+	10 YR 4/4	5 YR 4/4	M3P	Silt loam	SAB	Mf	Ms mp		-		Many
ODI2												
Ap	0 – 20	10 YR ¾			Fine silt loam	Cr	Fr	Ns, np	Many medium fine		Gradual smooth	Many
A	20 – 40	10 YR 5/4			Loam	WSAB	Sf	Ss sp	Many medium fine		Clear smooth	Common
B1	40 – 110	10 YR 5/3	5 YR 6/4	F2D	Silt loam	SAB	Sf	Ss sp	Common medium		Clear smooth	Common
B2	110- 141	7.5 YR 5/4	5 YR 4/4	M3D	Silt loam	SAB	Sf	Ss sp	Few medium		gradual smooth	Common
B3	141 – 180	7.5YR 5/2	5 YR 3/4	M3P	Silt loam	SAB	Sf	Ss sp			gradual smooth	Common
C	180 – 200+	10 YR 5/1	5 YR 3/4	M3P	Silt loam	SAB	Sf	Ss sp			Many carbon	Many
ODI3												
Ah	0 – 3	10 YR 2/2			Fine silt loam	cr	Vfr	Ns np	Many large medium fine		gradual smooth	Common
Ap1	3 – 20	10 YR 6/4	5 YR 5/3	C2D	Silt loam	VWSAB	Fr	Ns np	Many large medium fine		gradual smooth	Many
Ap2	20 – 46	10 YR 6/3	5 YR 5/4	C2D	Silt loam	WSAB	Sf	Ss sp	Common large		gradual smooth	Many
B1	46 – 60	10 YR 5/3	5 YR 4/6	C2D	Silt loam	SAB	Sf	Ss sp	Few large		gradual smooth	Many
B2	60 – 94	7.5 YR 4/4	5 YR 4/4	M2D	Silt loam	SAB	sf	Ss sp	Few large		gradual smooth	Many
B3	94 – 145	10 YR 4/6	5 YR 4/6	M3D	Silt loam	SAB	Sf	Ss sp			gradual smooth	Many

C1	145 – 158	10 YR 5/4	2.5 YR 5/2	M3P	Silt loam	SAB	Sf	Ss sp		Many carbon	gradual smooth	Many
C2	158 – 200+	10 YR 5/4	5 YR 5/3	M3P	Silt loam	SAB	Sfi	Ss sp		Many carbon		Many

<u>Abbreviations</u> :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent); WSAB=weak subangular blocky; SAB= subangular blocky; fr=friable; sf=slightly firm; mf=moderately firm; na= not sticky; np=not plastic; ss=slightly sticky; sp=slightly plastic; ms=moderately sticky; mp=moderately plastic

Table 3: Morphological Characteristics of the Koroama Soils

Horiz	Depth Cm	Soil Colour	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			colour	Pattern			Moist	Wet				
KRM1												
A1	0 – 7	10 YR ¾			Fine silt loam	Cr to WSAB	Fr	Ss sp	Many large medium fine	-	Clear smooth	Many
A2	7 – 43	10 YR 4/3			Silt loam	WSAB	Fr	Ss sp	Many large medium fine	-	Clear smooth	Many
B1	43 – 86	10 YR 3/2			Silt loam	SAB	Sf	Ss sp	Common large	Carbon	Clear smooth	Many
B2	86 – 115	10 YR 3/2			Silt loam	SAB	Sf	Ss sp	Few large	-	Clear smooth	Many
BC	115 – 130	10 YR 4/2	7.5 YR 4/4	M2D	Silt loam	SAB	Sf	Ss sp		Fe-Mn	Clear smooth	Many
C	130 – 200+	10 YR 4/3	10 YR 4/6	M3P	silt loam	SAB	Sf	Ss sp		-	Clear smooth	Many
KRM2												
Ap	0 -15	10 YR 3/2			silt loam	WSAB	Sf	Ns np	Many lerge medium fine	-	wavy	Few
Ap2	15 – 23	10 YR 5/3			silt loam	SAB	Sf	Ss sp	Many lerge medium fine	-	Clear smooth	Many
B1	23 – 40	10 YR 5/3			silty clay loam	SAB	Mf	Ms mp	Common lerge medium fine	-	Clear smooth	Many
B2	40 – 64	10 YR 4/3	5 YR 4/3	C2D	silty clay loam	SAB	Mf	Ms mp	Common lerge medium fine	-	Clear smooth	Many
B3	64 – 78	10 YR 5/3	5 YR 3/4	M3D	silt loam	SAB	Sf	Ss sp	Few large	-	diffuse wavy	Many
C1	78 – 140	10 YR 5/2	5 YR 3/4	M3P	silt loam	SAB	Sf	Ss sp	-	-	Clear smooth	Many
C2	140 – 194+	10 YR 5/1	7.5 YR 2.5/3	M3P	silt loam	SAB	Sf	Ss sp	-	-		Common
KRM3												
Ap	0 – 12	10 YR 3/2			fine silt loam	WSAB	Fr	Ns np	many large medium fine	-	Wavy	Few
Ap2	12 – 39	10 YR 5/2	5 YR 4/3	F2D	silty clay loam	SAB	Sf	Ss sp	many large medium fine	-	wavy	Few
B1	39 – 59	10 YR 2/2	5 YR 3/4	M2D	silt loam	SAB	Mf	Ss sp	many large medium	-	Clear smooth	Few
B2	59 – 96	10 YR 5/2	7.5 YR 4/6	M3D	silty clay loam	SAB	Mf	Ss sp	common large	-	Clear smooth	Few
B3	96 – 135	10 YR 5/2	7.5 YR 4/6	M3P	silty clay loam	SAB	Mf	Ss sp	Few large	-	Clear smooth	Few
C	135 – 190+	10 YR 5/2	7.5 YR 4/6	M3P	silty clay loam	SAB	Sf	Ss sp	-	-		Few

<u>Abbreviations</u> :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent); WSAB=weak subangular blocky; SAB= subangular blocky; fr=friable; sf=slightly firm; mf=moderately firm; na= not sticky; np=not plastic; ss=slightly sticky; sp=slightly plastic; ms=moderately sticky; mp=moderately plastic

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Table 4: Morphological Characteristics of the Niger Delta University Teaching and Research Farm Soils

Hor	Depth Cm	Soil Colour	Mottles		Texture	Structure	Consistence		Roots	Concret.	Boundary	Mica flakes
			clour	pattern			Moist	Wet				
NDU1												
Ap	0 – 19	10 YR 3/3			Fine silt loam	WSAB	sf	Ss sp	Many medium fine	-	Clear smooth	Many
B1	19 – 39	10 YR 4/4			Silt clay loam	SAB	Sf	Ss sp	Many medium fine	-	Clear smooth	Common
B2	39 – 71	10 YR ¾			Silt clay loam	SAB	Sf	Ss sp	Common medium fine	-	Clear smooth	Many
B3	71 – 81	10 YR 5/4			Silt clay loam	SAB	Sf	Ss sp	Few medium	-	Clear smooth	Many
C1	81 – 138	10 YR 5/3	5 YR 4/4	M3D	Fine silt loam	WSAB	sf	Ss sp	-	-	Clear smooth	Many
C2	138 – 195+	10 YR 6/2	5 YR 4/4	M3P	Fine silt loam	WSAB	sf	Ss sp	-	-		Many
NDU2												
Ap	0 – 12	10 YR 4/4			Fine silty clay loam	WSAB	Fr to sf	Ss sp	Many medium fine	-	Clear smooth	Few
Ap2	12 – 26	10 YR 4/4			Silty clay loam	SAB	Sf	Ss sp	Common medium fine	-	Clear smooth	Few
B1	26 – 36	10 YR 5/3			Silty clay loam	SAB	Sf	Ss sp	Few medium	-	Clear smooth	Few
B2	36 – 53	10 YR ¾	5 YR 3/3	M3D	Silty clay loam	SAB	sf	Ss sp	Very Few medium	-	Clear smooth	Few
B3	53 – 116	10 YR 5/4	5 YR 5/3	M3P	Clay loam	SAB	Sf	Ss sp	-	-	Clear smooth	Many
C	116 – 190+	10 YR 6/2	7.5 YR 3/4	M3P	Loam	SAB	sf	Ss sp	-	-		Many
NDU3												
A1	0 – 5	10 YR 3/3			Fine silt loam	WSAB	sf	Ss sp	Many medium fine	-	Clear smooth	Common
A2	5 – 13	10 YR 4/1	5 YR 5/3	M3D	silt loam	WSAB	sf	Ss sp	Many medium	-	Clear smooth	Common
AB	13 – 20	10 YR 4/4	5 YR 5/4	M3P	silt loam	WSAB	sf	Ss sp	Few medium	-	Clear smooth	Many
B1	20 – 75	10 YR 5/4	5 YR 4/3	M3P	silt loam	SAB	sf	Ss sp	-	-	Clear smooth	Many
B2	75 – 140	10 YR 5/4	5 YR 6/2	M3P	silt loam	SAB	Mf	Ss sp	-	-	Clear smooth	Many
C	40 – 196+	10 YR 6/3	5 YR 6/1	M3P	silt loam	SAB	Mf	Ss sp	-	-		Many

Abbreviations :Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The centre number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent); WSAB=weak subangular blocky; SAB= subangular blocky; fr=friable; sf=slightly firm; mf=moderately firm; ss=slightly sticky; sp=slightly plastic.

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down the ODI3 profile might not be unconnected with change in particle size distribution. Though the soil textural class is silt loam, clay content in the last two horizons was higher than the rest of the horizons.

Physical Characteristics

The soils of ODI and KRM were dominated by silt sized particles followed by sand and then clay and in the case of NDU, silt-sized particles also dominated the particle size distribution followed by clay and then, sand (Figure 2). Silt/clay ratio in the Koroama soils varied from 4.1 to 4.6 with mean as 4.4 for KRM1, 1.9 to 7.4 with 5.4 as mean for KRM2 and 4 to 6 with 5.4 as mean for KRM3. Silt loam textural class dominated the ODI soil textural class. From the surface layer of ODI3 to the bottom, all the horizons were silt loam while ODI2 had loam as textural class of the first two layers and silt loam in the remaining layers. The textural class of ODI1 soil varied between silt loam and loam down the profile (Figure 2). Dissimilarity in the trend of texture of soils has been attributed to differences in parent material and topography (Abua, 2012). The textural class distribution of the soils from Odi showed no marked variation which means the chemical and physical characteristics of the parent materials were not very different. Whereas ODI3 was silt loam from surface to bottom of the profile, ODI1 and ODI2 soils varied between silt loam and loam (Figure 2). Silt/clay ratios in the Odi soils ranged from 2.1 to 5.4 for ODI1, 3.2 to 4.8 for ODI2 and 3.3 to 7.1 for ODI3, suggesting that the soils were still very young and were yet to undergone ferralitic pedogenesis.

Using the ratings of Hazelton and Murphy (2007), silt was rated high in the surface and subsurface layers of all pedons, sand low to moderate in the surface layers of KRM2 and KRM3, and clay rated low to moderate in the surface and subsurface layers of KRM2 and KRM3 (Figure 2). The high silt content recorded for these soils agreed with the report of land Resources Development for Lower Niger River floodplains. Moreover, Abua (2012) reported that soils having silt fraction greater than 15% for both top and sub soils indicated that such soils have strong surface aggregation and may not be vulnerable to erosion hazard. The silt concentrations of Koroama soils (KRM1, KRM2 and KRM3) at the top and sub soil layers were far higher than 50% which may well mean that these soils have strong surface aggregation and might not be not vulnerable to erosion. Among the profiles, the lowest clay content was recorded in KRM2 (9%) and the highest in KRM3 (30%). Though increased clay concentrations were noticeable in the lower layers of KRM2 and KRM3, no cutans were found which indicated that the increased clay was not connected to clay illuviation but in-situ weathering of parent materials. As in other cases, sand, silt and clay distribution in the profiles showed irregularity which might not be unconnected with sediments types having different textures deposited yearly according to their sources (Azagaku and Idoga, 2012). Textural class distribution in the Koroama soil profiles also showed silt loam as the dominant textural class. However, slight variation in textural class distribution down the profile occurred in KRM2 and KRM3 (Figure 2). In KRM2, texture varied from silt loam in the first two top layers to silty clay loam in the two layers that followed and to silt loam in the succeeding layers. In KRM3, texture similarly varied from silt loam in the surface two layers to silty clay loam

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in the following layers back to silt loam in the succeeding layer. This again confirmed that different sediment types having different textures were deposited yearly according to their sources form the parent materials of Koroama soils.

Using Hazelton and Murphy (2007), ratings, silt is rated high for all the layers in all the pedons, clay is rated low to moderate in the top and sub soil layers of NDU1 and NDU2 but low in NDU3 while sand is rated low in all the pedons (Figure 2). Since the silt concentration in both top and subsoil layers in all the pedons is far above 50%, the NDU soils may have strong surface aggregation and have qualities that resist erosion hazard. Abua (2012), reported that soils with silt fractions greater than 15% for both top and sub soils is an indication of soil having strong surface aggregation and such soil may not be vulnerable to erosion hazard. Across the soil profiles, NDU1 recorded the lowest (7%) and highest (30%) clay concentration. Though increase in clay concentration was noticed in the B-horizons of NDU2 and NDU3, no cutans presence was observed. The clay increase recorded in those horizons might not be connected to agillation but in-situ weathering of the parent materials. Sand, silt and clay distribution in the profiles were irregular which might be traced to different sediments types having different textures deposited yearly according to their sources (Azagaku and Idoga, 2012). Silt loam class dominated the soil textural class distribution followed by silty clay loam in the NDU soils. For instance, NDU3 was silt loam all through the profile while in NDU1 and NDU2, texture varied from silt loam to silty clay loam and to silt loam. Silt/clay ratios of NDU soils ranged from 2.0 to 10.4 for NDU1, 1.9 to 5.0 for NDU2 and 3.5 to 4.9 for NDU3 which are far above unity. The silt/clay ratios of NDU soils suggested that the soils were young.

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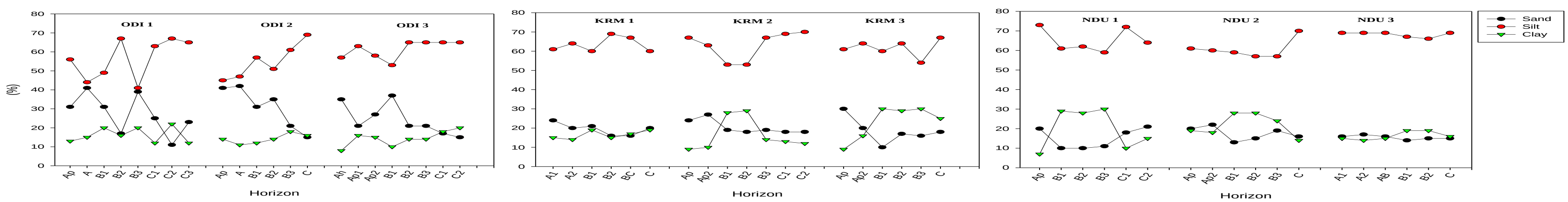

Figure 1: Percent sand, silt and clay in Odi, Koroama and Niger Delta University soils

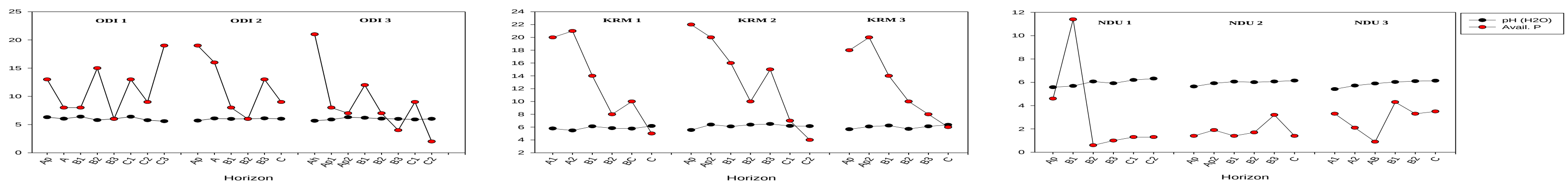

Figure 2: pH and available P in the Odi, Koroama and Niger Delta University soils

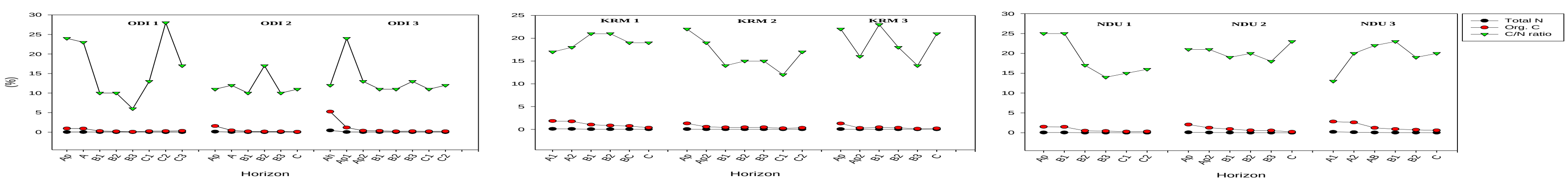

Figure 3: total organic, nitrogen and C/N ratio in Odi, Koroama and Niger Delta University soils

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Chemical Characteristics
The chemical properties of the soils are presented in figures 3 to 6. pH ranged from 5.64 to 6.30 in the surface layers and 5.99 to 6.30 in the subsurface layers. Available P (mg/Kg) varied from 6 to 21 in ODI soils, 4 to 22 in KRM soils and 0.6 to 11 in NDU soils (Figure 3). Organic C was 0.11 to 5.26% in ODI, 0.31 to 1.84% in KRM soils and 0.93 to 2.81% in NDU soils. Total N was 0.03-0.45% in ODI soils, 0.02 to 0.11% for KRM soils and 0.02 to 0.22% in NDU soils (Figure 4).

The pH values of the soils fall within the moderately acid to neutral classes (Figure 3) according to categorization by Fertilizer Procurement and Distribution Department (FPDD) (2012) and Jones (2003). FPDD categorization of Bayelsa State soils into pH classes indicated that soils with pH values between 5.0 – 5.5 are strongly acid, 5.6 -6.0 as moderately acid and 6.0 – 6.5 as slightly acid, 6.6-7.2 as neutral and 7.3-7.8 as slightly alkaline [20]. Using this categorization, the topsoil layers of NDU3 (5.42) and the subsurface layers of KRM3 (5.48) fall into strongly acid soil category while the remaining soils (surface layers of ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1 and NDU2 as well as the subsurface layers of ODI1, ODI2, ODI3, KRM1, KRM2, NDU1, NDU2 and NDU3) were slightly acid to neutral. The optimum pH for most agricultural crops as proposed by Wong et al (2001) fall between 6.0 and 7.0 as nutrients are more available at about pH 6.5. FAO (2006) and Brady and Weil (2005), gave a pH range of 5.5 to 7.0 as the preferred range for most crops because it is optimal for the overall satisfactory availability of plant nutrients. Using the classification by Jones, the top 40 cm layers and the subsurface soil layers were slightly acid to neutral. The results of this study showed noticeable increase in soil pH with increasing soil depth especially within the top 40 cm depth suggesting that there was leaching loss of nutrients with the heavy rainfall experienced in the area. This agreed with the findings of Abate et al. (2014), who attributed increase in soil pH values with increase in depth to downward translocation of basic cations. On the other hand, Khan et al (2012) attributed it to ferrolysis which is acidification of topsoil caused by continual displacement of bases by ferrous ion during the reduction phase associated with annual flooding. Flooding occurs annually in this environment which comes with the long rainy season.

Available P concentration decreased with increase in soil profile depth in the ODI and KRM soils which revealed the close relationship between organic matter and soil P. However, this was not the case in the NDU soils (Figure 3). McCauley et al. (2017), identified organic matter as the principal source of soil P for many soils [27]. The low available P levels recorded for NDU1, NDU2 and NDU3 might be attributed to high exchangeable acidity in these soils in comparison to total exchangeable bases. Abate et al. (2014), in a study of soils along a toposequence in Ethiopia recorded that available P increased down the topographic position and decreased with depth which they attributed to increasing clay content and decreasing soil organic matter content. In this study, soil organic matter content in the various horizons showed positive relationship with available P as both of them decreased with depth indicating that P decrease was due to decreasing concentration of organic matter with depth. FPDD (2012) rating for available P (Bray-1-P) for

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Bayelsa Soils was ‹3-very low, 3-7 low, 7-20 moderate and ›20 high. Using the FPDD ratings, available P level in the ODI and KRM soils generally, were moderate while those of NDU low. The distribution of P in the profiles showed no regular pattern of decrease which agreed with the findings of Nuga et al. (2006). This could be due to P fixing capacity and the slow release by the soils as a result of the relatively high level of iron and aluminium oxides in the soils. Low P availability in tropical soils attributed to the nature of the chemical forms of soil P and the high content of oxides of Fe and Al which are associated with high P fixation. Consequently, P is likely to be one of the most limiting nutrients for crop production in these soils.

The total N distribution in the profiles decreased generally with increase in depth (Figure 4) revealing that organic matter is the main source of total N in the soils. Relationship between organic C and total N has been established (Adeyanju, 2005). The total N contents of the studied soils were directly associated with organic C contents along soil profile depths, as the highest (0.45%) value was recorded in the surface layer of ODI3 soil designated ‘Ah’ where the highest organic C content (5.25%) was recorded. The total N content in all locations were higher in the surface soil layers than the underlying horizon, which is attributed to higher organic C contents in the surface. The higher total N content in the layer underlying the surface layers may be attributed to long-term cultivation coupled with frequent burning of crop residues (a common land clearing practice for cultivation) which accelerated the rapid turnover rates of organic materials under cultivation since total N in the soils is closely associated with organic C. Studies in Ethiopia (Habtamu et al., 2009; Alemayehu et al., 2014), confirmed that bush burning and removal of crop residue significantly reduce soil organic carbon and total N contents as cultivated and uncultivated land were compared. This indicated high N release from the organic matter sources since soil N is positively associated with soil organic matter content. On the other hand, when compared to the ratings by FPDD (2012) for Bayelsa State (0.3-0.5, very low, 0.6-1.0, low. 1.1-1.5, moderately low, 1.6-2.0. medium and 2.1-2.4, moderately high, the total N level in the samples was very low. The low N values recorded may be associated with high rate of organic matter mineralization and leaching coupled with intermittent flooding and drying which is known to favour N loss through nitrification-denitrification processes (Brady and Weil, 2005).

In another development, Hartz (2007), reported that soils with less than 0.07% total N have limited N mineralization potential, whereas those having total N values greater than 0.15% would be expected to mineralize sufficient amount of N during the succeeding crop cycle. Using the Hartz ratings of ‹0.07% total N, the surface 40 cm depth of ODI3, KRM1, NDU2 and NDU3 have high mineralization potential while, ODI1, ODI2, KRM2, KRM3 and NDU1 have low mineralization potentials (Figure 3). Furthermore, using the ›0.15% rating, only the surface 40cm depth of ODI3 is expected to mineralize sufficient amount of N during the succeeding crop cycle which is not good for the succeeding crops. Most of the soils may therefore require N applications for successful crop production during each crop cycle.

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The results of carbon to nitrogen ratio (C/N) showed irregular distribution with soil depth and topographical position in most of the soils (Figure 4). In most layers of the soils (ODI1, KRM1, KRM2, KRM3, NDU1, NDU2 and NDU3), C/N ratio especially in the plow zone was relatively higher than the common range (8:1 – 15:1) proposed by Brady and Weil (2005) for arable soils. Using the 'optimum' range (10:1 – 12:1) for arable soils (Havlin et al., 2006) only ODI2, and ODI3 soils were within the range which means oxidation and loss of organic matter in the plow layers of the other SMUs was not very rapid which is safe for the soils considering the important role organic matter plays in the retention of soil nutrients.

The exchangeable bases (Ca, Mg, K and Na) as presented in figure 5 indicated that Ca^{++} dominated the exchange complex. When the mean values obtained in this study were compared with FAO (2006) ratings for Ca^{++} and Mg^{++}, the results indicated that surface 40 cm and subsurface exchangeable Ca^{++} in soils were very low while exchangeable Mg^{++} contents were low to medium. Tisdale et al. (2004) attributed low exchangeable bases in soils (Ca, Mg, K and Na) to acidifying properties of organic matter, high aluminium concentration and leaching loss of exchangeable bases [34]. The low exchangeable Ca and Mg in the soils was attributed to lack of ferromagnesian minerals, low nutrient retentive capacity, high exchangeable Al and Fe and leaching loss of the nutrients due to high rainfall. The X-ray diffraction results reported by Dickson (2018) on these soils indicated that these soils were low in ferromagnesian minerals. Biotite and vermiculite were the only ferromagnesian minerals and their concentrations were low. Biotite was found in low concentrations in KRM1 only while vermiculite was detected in all the samples though in small concentrations. The absence or low concentration of the ferromagnesian group of minerals known to supply Ca and Mg to soils probably was the main reason for the low levels of the nutrients.

Appropriate Ca/Mg ratios in soils will improve soil structure, reduce leaching loss of other nutrients, reduce weed population and generally improve the balance of most nutrients (Sharu et al., 2013). It has been reported also that, under gleization process of soil formation, exchangeable Mg^{2+} becomes the dominant cation in the exchange complex (Khan et al., 2012). From the results, the Ca^{2+}/Mg^{2+} ratio of ODI1 (subsurface) ODI2 (subsurface), KRM1 (subsurface), KRM2 (subsurface), KRM3 (subsurface) NDU1 (surface and subsurface) and NDU2 (subsurface) fell below the "optimum" (2 – 4:1) value as proposed by Landon (1991), for most crops. Landon reported that Ca^{2+}/Mg^{2+} ratio below 3:1 results in unavailability of Ca and limitation of Ca uptake by crops due to excess amount of Mg. In this case, only ODI1 (surface), KRM1 (surface) and NDU3 (subsurface) would meet Landon's ratio of 3:1. It is possible the alluvial deposits from which these soils were formed were low in exchangeable Ca as the soils were considered to be in their early stages of development. The Ca^{2+}/Mg^{2+} ratio of less than unity indicated loss of Ca^{2+} due to gleization (Khan et al., 2012).

Exchangeable K in the soils, unlike exchangeable Ca and Mg varied from low to very high (FAO, 2006). According to FAO (2006) rating for exchangeable K, soils with exchangeable K greater than 1.2 is very high, 1.2 - 0.6 high, 0.6 – 0.3 medium, 0.3 - 0.2 low and less than 0.2 very low.

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The K concentrations in most of the KRM and NDU soils further away from the Niger River were low to medium while ODI soils closer to the Niger River were medium to high. This development is difficult to explain since mica flakes presence was recorded in all the profile pits. This development might be attributed to lack of ferromagnesian minerals in the soils. It is important to note that the presence of muscovite was dominant over biotite in the soils. However, some level of variation in the distribution of basic cations down the profiles was observed which is attributed to differences in the source of the alluvial materials that formed the horizons rather than movement of nutrients from the top to the lower horizons since these soils were young and there was no marked clay illuviation.

Sum of the exchangeable bases in the soils (Figure 6) was low which reflected the low concentration of basic cations in the soils (Figure 5). Effective cation exchange capacity of the soils across the SMUs was generally low when compared to the figures given by Esu (1991). Esu recorded low exchangeable bases in Hadejia alluvial complex in Nigeria and attributed it to low CEC. Low values of Ca, Mg and K have however been reported for most Nigerian soils (Akinirinde and Obigbesan, 2000; Uzoho et al., 2007), which was attributed to leaching losses by the high tropical rainfall as well as low content in the parent rock. The ECEC values recorded in this study were lower than the 15 cmol/kg reported by Udo et al. (2009), as the critical ECEC value for tropical soils. The base saturation values of the surface layers of most of the pedons are below 50% and >50% base saturation is regarded as high (Senjobi et al., 2019). This shows that the does have have high basic cations because the kaolinitic clay content has low capacity to adsorb cations (Senjobi et al. 2019). Also, the CEC values in this study (2.38-7.14 cmolkg^{-}1) were very low. However, most of the soils have ECEC (cmolkg^{-1}) values of 4 and above which was the value Sanchez considered as having the ability to withstand heavy leaching losses of nutrients in tropical soils (Sanchez, 1979). Sanchez in his book on “Properties and Management of Soils in the Humid Tropics asserted that tropical soils with ECEC values of 4 cmolkg^{-1} and above could withstand heavy leaching loss of nutrients. From the figures above, majority of soils in the surface 40 cm depth have enough ECEC to withstand heavy leaching loss of nutrients.

Out of the 59 samples, the exchangeable acidity values of 53 samples were below the critical value of 2.0 cmolkg^{-1} (Figure 6) which indicated slightly to moderately acid nature of the soils [41] Ernest and Onweremadu, 2016). The acidic nature could be attributed to the humid nature of the environment which is characterized by intense rainfall and its leaching effect. This may account for the low concentration of exchangeable bases in the soils. Since the alluvial soils were of sedimentary origin and may not have gone through very prolonged period of weathering and leaching loss of basic cations, it is possible that the parent materials from which the soils were formed have acid characteristics. Aluminum ions cause acidity by hydrolysis reaction while hydrogen is by direct dissociation (Brady and Weil, 2005). Generally, exchangeable Al distribution down the profiles studied was irregular, suggesting no movement of Al from the surface to the bottom layers, corroborating the fact that the soils were in their early stages of development. Moreover, exchangeable H contributed more to the total exchangeable acidity of the soils studied

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than exchangeable Al which may well mean that weathering was not advanced enough to release more quantity of Al to the soils. Since meander belt soils are in their early stages of soil development, corroborated by the high silt/clay ratios recorded for all the soils, the low to moderate Al saturation level recorded for the soils was more likely to be from the alluvial deposits that formed the soils other than in-situ weathering of the deposits.

Classification of the soils

All the SMUs belong to the Iso hyperthermic temperature regime and udic moisture regime with profile development still at the early stages as indicated by the high silt/clay ratios. Organic carbon content decreased irregularly with increase in soil depth. The fact that no other diagnostic horizon was present except ochric epipedon and Cambic B-horizon for all the pedons met the requirements for the inceptisol order.

The ODI1soils lay content increased from A to B horizon but no cutans present which satisfied the conditions of Cambic B-horizon while no other subsurface horizon was present except ochric epipedon. This pedon is placed in the Udepts suborder since the area belonged to udic moisture regime and the Great group level, Dystrudepts because it has base saturation of less than 60% in all the sub horizons between the depths of 25 and 75 cm. At the Subgroup level, Humic Dystrudepts was given because it has a cambic horizon with base saturation (by sum of cations) of 35% or more at a depth of 125 cm from the top of the cambic horizon while according to the Reference Soil Group of the World Reference Base (RSG-WRB), it is classified Fluvic Cambisol (Dystric-greyic). The ODI2 soils is classified into the Udepts Suborder and Dystrudepts as the Great group because base saturation was less than 60% in most of the horizons between 25 and 75 cm depth. At the Subgroup, Aquic Dystrudepts was given because in all normal years, the pedon seems to be saturated with water from 40 cm depth and below Fluvic Cambisol (Dystric-siltic) is given according to RSG-WRB. The ODI3 was placed in the Aquepts Suborder due to the presence of redoximorphic features from 5 cm down the profile. The Great Group of ODI3 is Epiaquepts because of ground water saturation of the profile from 5 cm to below 200 cm while Aeric Epiaquepts at the Subgroup is given level because the base saturation (by NH_4OAc) was less than 50% in some horizons within 100 cm depth of the pedon while Fluvic Cambisol

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Table 5: Classification of the Soils using Soil Taxonomy and Reference Soil Group of the World Reference Base

Classification					
S/No	**Pedon**	**Drainage[1]**	**Soil Taxonomy Sub group**	**Family[2]**	**RSG-WRB**
1	ODI1	WD	Humic Dystrudepts	fine, silt loam over loam	Fluvic Cambisol (Dystric-greyic)
2	ODI2	MWD	Humic Dystrudepts	silt loam over loam	Fluvic Cambisol (Dystric-siltic)
3	ODI3	PD	Aeric Epiaquepts	fine, silt loam	Fluvic Cambisol (Dystric-siltic)
4	KRM1	WD	Udic Dystropepts	fine, loam	Humic-fluvic Cambisol (Dystric-siltic)
5	KRM2	MWD	Aquic Dystrudepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
6	KRM3	PD	Typic Epiaquepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
7	NDU1	WD	Udic Dystropepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-greyic-siltic)
8	NDU2	MWD	Aquic Dystrudepts	fine, silt loam over silty clayloam	Fluvic Cambisol (Dystric-siltic)
9	NDU3	PD	Fluvaquentic Endoaquepts	fine, silt loam	Fluvic Cambisol (Dystric-greyic-siltic)

1 MWD= moderately well drained; WD= well drained; PD= poorly drained
2 All belong to the iso-hyperthermic temperature regime

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(Dystric-siltic) is given according to RSG-WRB.
The KRM1 soil is placed Tropepts Suborder due to the iso-hyperthermic temperature regime of the soil while the Great group Dystropepts is given because at the depth between 25 and 75 cm, the base saturation (by NH_4OAc) was less than 60%. The Subgroup Udic Dystropepts is given because it belonged to the udic moisture regime and redoximorphic features were observed below 100 cm depth which correlated with Humic-fluvic Cambisol (Dystric-siltic) according to RSG-WRB. In the case of KRM2, since the moisture regime is Udic, it is placed in the Udepts Suborder and into the Great group, Dystrudepts because of the acid pH and a base saturation of less than 60% (by NH_4OAc) in the sub horizons between 25 and 75 cm below the soil surface. The pedon seem to be water saturated in three horizons within 100 cm of the mineral soil surface which qualified it to be placed in the Aquic Dystrudepts Sub Group which correlated with Fluvic Cambisol (Dystric-greyic-siltic) in the RSG-WRB system. The KRM3 soils is classified into the Suborder, Aquepts and the Great group Epiaquepts because of low exchangeable sodium percentage and fluctuation of ground water from a level near the surface to below 200 cm. The Subgroup was Typic Epiaquepts because organic carbon content was less than 0.2% at a depth of 125 cm and below the soil surface and the decrease in organic carbon down the profile which correspond with Fluvic Cambisol (Dystric-greyic-siltic) in the RSG-WRB.

The Suborder of NDU1 is Tropepts due to the isohyperthermic temperature regime of the soil while the Great group Dystropepts is given because the base saturation of the soil from the soil surface down to 75 cm depth was less than 60%. Furthermore, it is classified into Udic Dystropepts Subgroup because it is under udic moisture regime. The RSG of NDU1 in the WRB classification system was Fluvic Cambisol (Dystric-greyic-siltic). The NDU2 is placed in the Suborder Udepts due to the udic moisture regime, the Great group Dystrudepts because base saturation from the surface layer to 116 cm depth was less than 60% and the Subgroup Aquic Dystrudepts because at certain periods of the year, the pedon seem to be saturated by ground water from 36 cm from the surface down to below 200 cm. The correlating RSG in the WRB system is Fluvic Cambisol (Dystric-siltic). The NDU3 soils is placed Suborder Udepts due to the udic moisture regime and the Great group Dystrudepts because base saturation from the surface layer to 116 cm depth was less than 60% and the Subgroup Aquic Dystrudepts because at certain periods of the year, the pedon seem to be saturated by ground water from 36 cm from the surface down to below 200 cm while according to RSG-WRB, it is Fluvic Cambisol (Dystric-greyic-siltic).

CONCLUSION

The Nun River floodplain alluvial soils derived from sedimentary materials transported by the Niger River, through southern Nigeria to the Atlantic coast, are characteristically dominated by sand and silty materials. The soils are weakly structured varying from crumbly to weak subangular blocky especially in the upper layers of the profiles. Similarly, soil consistence is dominantly friable or slightly firm and non-sticky, non-plastic to slightly sticky and slightly plastic, especially in the upper layers. Generally, there were variations in soil properties within soil profiles, among physiographic units and study locations. It is therefore, imperative for soil management practices to be site specific which should cater for the physiographic position of the soil and location.

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