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Characterization and classification of some Alluvial soils of the Lower Niger River floodplains in Bayelsa State, Nigeria

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Abstract

For increased agricultural production, the place of adequate knowledge of soil properties and reliable soil data in the management of floodplain soils cannot be down-played. This study therefore, was conducted with the objective of characterizing and classifying some alluvial soils of the lower Niger floodplain in Bayelsa State, Nigeria to provide current and reliable data. Nine representative soil pedons were opened on various landscape positions, including levee crest, middle slope, lower slope and/or recent alluvial soils in the channel of the present active river in the three locations, described in the field and horizon-wise samples collected for morphological and physico-chemical analysis. The soils were deep, variation in soil colours (moist) within and among pedons in the different landscape locations very obvious as very dark grayish brown, very dark brown, dark brown, dark yellowish brown, and brown colours, dominated the surface and subsurface layers. Silt loam was the predominant soil texture. Soils were strongly acid to neutral [pH (H_2O), 4.94-7.00], very low to medium organic matter (0.13-4.02%) and total N (0.01-0.25%) contents, low to moderate available P (3-21 mgkg^{-1}), low to very high (0.10-2.13 cmolkg^{-1}) exchangeable K and low CEC (1.49-8.06 cmolkg^{-1}). The soils were classified as Aquic Dystrudepts, Typic Epiaquepts, Eutric Udifluvents, Humic Dystrudepts, Fluvaquentic Epiaquepts and Aquic Udifluvents using the USDA Soil Taxonomy and Fluvic Cambisol, Haplic-Fluvic Fluvisol and Haplic Fluvisol according to the WRB legend. Wetness, flooding, and soil chemical and physical fertility challenges were major constraints to increased and sustainable crop production in these soils.

Key words: morphology, characterization, classification, floodplain soils, Lower Niger River

Introduction

Floodplain soils, worldwide, are very useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants (Akpan-Idiok & Ogbaji, 2013). However, the agricultural potentials of alluvial soils have not been fully exploited because of lack of understanding of their physical and chemical properties and the changes they undergo under intensive cultivation (Effiong & Ibia, 2009). The floodplain soils of Bayelsa state for instance, are intensively cultivated due to population increase and pressure on available land space. This is exacerbated by climate change and the extreme flooding experienced in recent times where the levee crest soil which hitherto was not flooded according to (Okonny et al., 1999) is now flooded annually. With the changes that are taking place due to climate change and flooding, it is obvious that information and knowledge on these soils must be improved as Dickson (2018) reported that information and knowledge on the characteristics, capabilities and suitability are not current, inadequate and obsolete. Hence, the efficient management of the soils for increase and sustainable crop production is constrained. Consequently, Bayelsa state cannot meet the food needs of the populace, depending on other states for food. With the present drive of the world towards food security, the state cannot be left behind and the government is working towards agricultural intensification in various parts of the state which cannot be achieved with the present level of information and knowledge on the soils. This study therefore, was conducted to characterize and classify the soils to generate current and adequate information that can determine the agricultural suitability of soils of the selected communities earmarked by the Bayelsa State government for agricultural intensification.

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. The Niger River traverses Nigeria in a North-western to Southern direction with the attendant sediment load ensuring that the delta platform ends up as flat terrain, making it a unique geologic environment. The Niger River flows southward and breaks up into two - the Forcados and Nun Rivers in Bayelsa State, the Nun River, running north and south down the middle of the Bayelsa State, which remains the most direct tributary of the Niger while Forcados River demarcates the western borders of the state. The Elemebiri community by the Lower Niger River, Odoni by Nun River and Trofani by the Forcados River (Fig. 1) were chosen for the study due to the proposed agricultural intensification. In the study area, the annual rainfall (2000-4500 mm), spread over 8 to 10 months of the year is bimodal, peaking at June and September. The relative humidity averages 80% all over the state and temperature is fairly constant with a maximum of 30^{o} C. The natural vegetation is tropical rainforest. Food is cultivated on the levee crest, levee slope, back slope and on recent alluvial soils on channels of present active rivers. 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 River floods.

Field Studies

Detailed soil survey was conducted on agricultural lands from Elemebiri, Odoni and Trofani using rigid grids. The designation of the soil mapping units (SMUs) were ELM1, ELM2 and ELM3 for Elemebiri, ODN1, ODN2, and ODN3 for Odoni soils and TFN1, TFN2 and TFN3 for Trofani, Details of the soil mapping units and the land area are presented in Table 1. Soil sampling procedures followed the methods prescribed by the USDA Soil Taxonomy and the World Resource Base. Three representative soil pedons were dug per location, one each on the levee crest, levee slope and flood plain or recent alluvial soils in the channel of the present active river. The soils were morphologically described in-situ and samples collected from the different horizons for physico-chemical properties following standard procedures. Using the geographic positioning system (GPS), coordinates of each SMU boundaries and profile pit locations were taken during the field survey while digital camera was used to capture the profile pits and surrounding environment. The soil samples collected were air-dried, crushed and sieved to pass through a 2 mm mesh.

Laboratory Analyses

The soils were analysed in the Green River Project laboratory of the Nigerian Agip Oil Company and Zadell laboratory, Port Harcourt, Nigeria. Standard laboratory methods were used to determine the physical and chemical properties of the soil samples. Soil particle size analysis was determined using (Day, 1965) method, popularly known as hydrometer method. Soil pH both in water and $CaCl_2$ (1:2 ratio) was determined using glass electrode pH meter and electrical conductivity determined using conductivity meter (Estefan et al., (2013). Organic carbon was determined using the modified dichromate oxidation method of Walkley-Black as described by Estefan et al. (2013) and the values obtained multiplied by 1.724 to obtain organic matter, total N was determined using macro-kjeldahl digestion-distillation method as described by Houba et al. (1995) and available P by Bray P-1 method (Bray & Kurtz, 1945). Exchangeable acidity was extracted with 1M KCl and determined by titration with NaOH solution using phenolphthalein indicator (Anderson & Ingram, 1993) and exchangeable Al with 0.01 M HCl (Sumner & Stewart, 1992). Exchangeable cations were extracted with neutral normal ammonium acetate solution as described by (Estefan et al., 2013) and potassium and sodium in the extract measured by flame photometry and calcium and magnesium by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was by the summation method (Kamprath, 1970). The soils were classified using the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Resource Base (FAO/ISRIC, 2006).

Results and Discussions

Organic matter content in the soils generally was low to moderate, ranging from 0.19-3.88%, 0.13-4.02% and 0.37-2.76% for the Elemebiri, Odoni and Trofani soils, respectively. Total N was also low to moderate ranging from 0.01 to 0.25% in Elemebiri soils, 0.01-0.21 in the Odoni soils and 0.01 to 0.13% in the Trofani soils (Tables 3a, b, c). Furthermore, exchange acidity varied from 0.5-2.8 cmol/kg in the Elemebiri soils, 1.1-6.2 cmol/kg in the Odoni soils and 0.8-5.4 cmol/kg in the Trofani soils while exchangeable Al ranged from 0.3-1.9 $cmolkg^{-1}$ in the Elemebiri soils and 0.7-3.6 $cmolkg^{-1}$ in the Odoni soils, and 0.5-2.4 $cmolkg^{-1}$ in the Trofani soils. Also, the ECEC values were low, ranging from 1.49-6.11 $cmolkg^{-1}$ in Elemebiri soils, 2.47-8.06 $cmolkg^{-1}$ in Odoni soils, and 2.79-6.37 $cmolkg^{-1}$ in Trofani (Tables 3a, b, c). Exchangeable Ca^{2+} dominated the exchange complex of the SMUs followed by Mg^{2+}.

Soil Morphological Properties and Drainage

The morphological characteristics of the Elemebiri, Odoni and Trofani soils are presented on Tables 2 and 3, respectively. The ELM1, ODN1 and TFN1 profiles were located on the levee crest, ELM2, ODN2 and TFN2 in the middle slope and ODN3 on the lower slope while ELM3 and TFN3 were located on alluvial soils on the channel of present active Niger river and Forcados river, respectively. Generally, colour variation within and among profile locations was very obvious as surface soil colour (moist) of ELM1 was very dark grayish brown (10 YR 3/2), dark brown (7.5 YR 4/4) for ODN1 and dark yellowish brown (10 YR 3/4) for TFN1. In the middle slope soils, surface colour was very dark brown (10 YR 2/2) for ELM2, brown (7.5 YR 4/2) for ODN2 and dark brown (7.5 YR 3/3) for TFN2. The surface colour of ODN3 from the lower slope was dark brown (7.5 YR 3/2) while for the soils collected from alluvial soils in the channels of present active rivers, the surface soil colour of ELM3 was dark yellowish brown 10 YR 3/6) while that of TFN3 was dark brown (10 YR 3/3). For the subsurface soil layers, colour graded from dark brown (10

Table 1. Georeferenced Coordinates and Land Area of the Study areas

Location	Soil Mapping Unit	Geo-reference of Profile Pit	Land Area (ha)
Elemebiri	ELM1	N 05° 21’ 11.5” E 006° 30’ 02.2”	29.0788224
	ELM2	N 05° 21’ 12.4” E 006° 30’ 51.3”	21.2464612
	ELM3	N 05° 21’ 22.6” E 006° 30’ 51.3”	162.139097
Odoni	ODN1	N 05° 14’ 12.4” E 006° 22’ 37.2”	89.943181
	ODN2	N 05° 14’33.3” E 006° 22’ 25.5”	52.099569
	ODN3	N 05° 14’ 53.3” E 006° 22’ 43.4”	90.573750
Trofani	TFN1	N 05° 18’ 01.5” E 006° 19’ 36.0”	87.610710
	TFN2	N 05° 17’ 58.6” E 006° 19’ 37.1”	51.495672
	TFN3	N 05° 18’ 17.1” E 006° 19’ 41.2”	148.509325

YR 3/3) through dark yellowish brown (10 YR 3/4), yellowish brown (10 YR 5/4) to brown (10 YR 5/3) for ELM2, dark brown (7.5 YR 3/2) through brown (7.5 YR 4/2), strong brown (7.5 YR 4/6) to brown (7.5 YR 4/4) for ODN2, brown (7.5 YR 4/4) through pinkish gray (7.5 YR 6/2), brown (7.5 YR 5/4) strong brown (7.5 YR 5/6) to brown(7.5 YR 4/6) for ODN3 and dark yellowish brown (10 YR 4/4) through grayish brown (10 YR 5/2), brown (10 YR 5/3), (10 YR 5/2) to light brownish gray for TFN2. In the subsurface layers of ELM3, colour graded from dark brown (10 YR 3/3) through light yellowish brown (10 YR 6/4), dark yellowish brown (10 YR 4/6), yellowish brown (10 YR 5/4), dark yellowish brown (10 YR 3/4), brown (7.5 YR 4/4) to very dark brown (7.5 YR 2.5/3) and for TFN3, colour graded from dark yellowish brown (10 YR 3/4) through yellowish brown 10 YR 5/4), dark brown (10 YR 3/3), light yellowish brown (10 YR 4/6), dark brown (10 YR 3/3) to pale brown (10 YR 6/3).

Hydromorphism was quite obvious with mottles observed in all the profiles though at various depths. There was occurrence of few, medium, distinct, reddish brown mottles (5 YR 4/4) at the 21-34 cm depth of the subsurface soil layer of ELM1 (Table 2), which was attributed to the alluvial source from which the soil layer was formed while in ODN1, reddish brown, and yellowish red mottles were observed on the surfaces of the two lowest horizons. In TFN1, redoximorphic features were observed from 140 cm depth. Redoximorphic characteristics were also observed at the two lowest layers of the ELM1 profile, as few, medium, distinct, brown (7.5 YR 5/6) and common, medium distinct, yellowish red (5 YR 4/6) mottles were present which indicated that the two layers came under ground water influence during the rainy season each year. These two soil layers are subject to ground water influence during the annual floods, starting May/June, peaking in September/October and recedes later in October to early November. One spectacular observation in the river plain soils was redoximorphic characteristics at various depths of the pedons depending on the location of the soil on the landscape. As one moves from levee crest to middle slope to lower slope, the depth at which redoximorphic features were observed reduced. The alternate wetting and drying conditions resulted in the reduction and subsequent release of iron oxides which accumulated in the form of reddish brown, brown and yellowish red mottles on the subsurface of the pedon (Akpan-Idiok & Ogbaji, 2013). Redoximorphic features are associated with flooding/wetness following alternating periods of reduction and oxidation of iron and manganese compounds in soils (Hossain et al., 2011). Dark colour in the upper layers of the ELM1 soil was attributed to organic matter coloration. All the studied profiles were considered hydromorphic because of the presence of mottles.

Table 2a. Morphological Characteristics of the Elemebiri Soils and their Classification

Horizon	Depth (cm)	Soil Colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary	Inclusions
			Colour	Pattern			Moist	Wet			
ELM1 (Aquic Dystrudepts/Fluvic Cambisol)											
Ap	0 – 8	10 YR 3/2			Fsil	Cr to WSAB	fr	Ss, Sp		Cs	Many mica flakes, Many medium to fine roots
Ap2	8 – 21	10 YR 3/3			Fsilcl	WSAB	Sfi	Ss, Sp		Cs	Many mica flakes, Many medium roots
B1	21 – 34	10 YR 3/4			Fsilcl	SAB	mfi	Ss, Sp		Cs	Common mica flakes, Common medium roots
B2	34 – 65	10 YR 3/4			Fsil	SAB	mfi	Ss, Sp	C	Cs	Many mica flakes, Common medium roots
C1	65 – 90	10 YR 4/4			Fsil	SAB	sfi	Ss, Sp		Cs	Common mica flakes, few medium roots
C2	90 – 118	10 YR 4/4			Fsilcl	SAB	sfi	Ss, Sp		Cs	Common mica flakes
C3	118 – 150	10 YR 5/4	7.5 YR 5/6	F2D	Fsil	SAB	sfi	Ss, Sp		Cs	Common mica flakes
C4	150 – 200	10 YR 5/3	5 YR 4/6	C2D	Fsil	SAB	sfi	Ss, Sp			Many mica flakes
ELM2 (Typic Epiaquepts/Fluvic Cambisol)											
Ap	0 – 11	10 YR 2/2			Fsil	Cr to WSAB	Fr	Ss, Sp		Cs	Many mica flakes, many medium to fine roots
Ap2	11 – 19	10 YR 3/3			Fsilcl	SAB	Mfi	Ss, Sp		Cs	Many mica flakes, many medium to large roots
B1	19 – 32	10 YR 3/2			Fsilcl	SAB	Mfi	Ss, Sp		Cs	Many mica flakes, common medium to large roots
B2	32- 42	10 YR 4/3			Fsil	SAB	Sfi	Ss, Sp		Cs	Many mica flakes, common large roots
B3	42 – 57	10 YR 5/3	7.5 YR 4/3		Fsil	SAB	Sfi	Ss, Sp		Cs	Many mica flakes, few large roots
B4	57 – 88	10 YR 5/2	7.5 YR 3/4	M2D	Fsilcl	SAB	Sfi	Ss, Sp		Cs	Many mica flakes
C1	88 – 106	10 YR 5/2	7.5 YR 4/6	M2D	Fsil	SAB	Sfi	Ss, Sp		Cs	Many mica flakes
C2	106 – 190	10 YR 5/1	7.5 YR 4/6	M2D	Fsil	SAB	Sfi	Ss, Sp			Many mica flakes
ELM3 (Eutric Udifluvents/Haplic-Fluvic Fluvisol)											
A	0 – 18	10 YR 3/6			Fsl	Cr	Vfr	Ns, Np		Cs	Many mica flakes, many medium fine roots
Ap1	18 -31	10 YR 3/3	2.5 YR 3/3	F2D	Fsl	Sg	Fr	Ns, Np		C	Many mica flakes, common medium fine roots
Ap2	31 – 44	10 YR 6/4	-	-	Ls	Sg	Fr	Ns, Np		C	Many mica flakes, few medium roots
C1	44 – 68	10 YR 4/6	-	-	Sl	Sg	Fr	Ns, Np		Cs	Many mica flakes
C2	68 – 81	10 YR 5/4	-	-	Sl	Sg	Fr	Ns, Np		Cs	Many mica flakes
C3	81 – 123	10 YR 3/4	-	-	Ls	VWSAB	Sfr	Ns, Np		Cs	Many mica flakes
C4	123 – 160	7.5 YR 4/4	-	-	Ls	SAB	Sfr	Ns, Np		G	Many mica flakes
C5	160 – 200	7.5 YR 2.5/3	-	-	Ls	VWSAB	Fr	Ns, Np			Many mica flakes

Keys: Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The center number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).; structure: Cr=crumbly, VWSAB=very weak sub angular blocky, WSAB=weak sub angular blocky, SAB=sub angular blocky, crumb=crumbly, sg=single grain; Texture: fsil=fine silt loam, sl=sandy loam, ls=loamy sand, fsl=fine sandy loam, fsicl=fine silty clay loam, Consistence: ns=non sticky, np=non plastic, ss=slightly sticky, sp=slightly plastic, fr=friable, sfi=slightly firm; mfi=moderately firm; concretion: c=carbon concretions; boundary: cs=clear smooth; g=gradual; *=all belong to iso-hyperthermic temperature regime.

Table 2b. Morphological Characteristics of the Odoni Soils and their Classification

Horizon	Depth (cm)	Soil colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary	Inclusions
			Colour	Pattern			Moist	Wet			
ODN1 (Humic Dystrudepts/Fluvic Cambisol)											
Ap	0 – 23	7.5 YR 3/2			Fsil	VWSAB	sfi	Ss, sp	-	Cs	Many mica flakes, Many, fine roots
Ap2	23 – 30	7.5 YR 4/4			Fsil	WSAB	sfi	Ss, sp	-	Cs	Many mica flakes, many medium roots
B1	30 – 63	7.5 YR 4/4			Fsil	SAB	mfi	Ss, sp	-	Dw	Common mica flakes, common large roots
B2	63 – 117	7.5 YR 4/6			Sil	SAB	mfi	Ss, sp	-	Dw	Common mica flakes, few large roots
B3	117 – 160	7.5 YR 4/3	5 YR 4/4	M3D	Sil	SAB	mfi	Ss, sp	-	Dw	Common mica flakes
C	160 – 200	7.5 YR 4/6	5 YR 4/6	M3P	Sil	SAB	mfi	Ss, sp	-		Common mica flakes
ODN2 (Typic Epiaquepts/Fluvic Cambisol)											
Ap	0 – 20	10 YR 3/4			Fsil	Cr	fr	Ns, np	-	Cs	Many mica flakes, many medium fine roots
A	20 – 40	10 YR 5/4			L	WSAB	sfi	Ss, sp	-	Cs	Common mica flakes, many medium roots
B1	40 – 110	10 YR 5/3	5 YR 6/4	F2D	Sil	SAB	sfi	Ss, sp	-	Cs	Many mica flakes, common medium roots
B2	110- 141	7.5 YR 5/4	5 YR 4/4	M3D	Sil	SAB	sfi	Ss, sp	-	Dw	Common mica flakes, few large roots
B3	141 – 180	7.5YR 5/2	5 YR 3/4	M3P	Sil	SAB	sfi	Ss, sp	-	Cs	Common mica flakes, few large roots
C	180 – 200	10 YR 5/1	5 YR 3/4	M3P	Sil	SAB	sfi	Ss, sp	-		Common mica flakes
ODN3 (Fluvaquentic Epiaquepts/Fluvic Cambisol)											
A	0 – 5	7.5 YR 3/2			Fsil	WSAB	sfi	Ss, sp	-	Dg	Common mica flakes, many medium fine roots
Ap1	5 – 11	7.5 YR 4/4	5 YR 5/3	C2D	Sil	WSAB	sfi	Ss, sp	-	Dw	Common mica flakes, many medium roots
Ap2	11 – 25	7.5 YR 4/4	5 YR 6/4	C2D	Sil	SAB	sfi	Ms, mp	-	Dg	Common mica flakes, common medium roots
B1	25 – 41	7.5 YR 6/2	5 YR 6/1	C2D	Sil	SAB	mfi	Ms, mp	Fe-Mn	Cs	Common mica flakes, common medium roots
B2	41 – 48	7.5 YR 4/4	5 YR 5/2	C2D	Sicl	SAB	mfi	Ms, mp	Fe-Mn	Cs	Common mica flakes, common medium roots
B3	48 – 56	7.5 YR 5/4	5 YR 4/4	M3P	Cl	SAB	mfi	Ms, mp	-	Cs	Common mica flakes, few large roots
C1	56 – 122	7.5 YR 5/6	5 YR 4/4	M3P	L	SAB	mfi	Ms, mp	-	Cs	Common mica flakes, few large roots
C2	122 – 200	7.5 YR 4/6	5 YR 4/6	M3P	L	SAB	mfi	Ms, mp	-		Common mica flakes

Keys: Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The center number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).; structure: Cr=crumbly, VWSAB=very weak sub angular blocky, WSAB=weak sub angular blocky, SAB=sub angular blocky, crumb=crumbly, sg=single grain; Texture: fsil=fine silt loam, sl=sandy loam, ls=loamy sand, fsl=fine sandy loam, fsicl=fine silty clay loam, Consistence: ns=non sticky, np=non plastic, ss=slightly sticky, sp=slightly plastic, fr=friable, sfi=slightly firm; mfi=moderately firm; concretion: c=carbon concretions; boundary: cs=clear smooth; g=gradual; *=all belong to iso-hyperthermic temperature regime.

Table 2c. Morphological Characteristics of the Trofani Soils and their Classification

Horizon	Depth (cm)	Soil colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary	Inclusions
			Colour	Pattern			Moist	Wet			
TFN1 (Aquic Dystrudepts/Fluvic Cambisol)											
Ap	0 – 14	10 YR ¾			Fsil	SAB	Sfi	Ss, sp		Cs	Many mica flakes, many medium fine toots
A	14 – 31	10 YR ¾			Fsil	SAB	Sfi	Ss, sp		Cs	Common mica flakes, few fine roots
B1	31 – 55	10 YR ¾			Fsil	SAB	Mfi	Ss, sp		Cs	Many mica flakes, few fine roots
B2	55 – 140	10 YR 3/6			Fsil	SAB	Mfi	Ss, sp		Cs	Many mica flakes
B3	140 – 150	10 YR 4/2	2.5 YR ¾	C2D	Fsilcl	SAB	Mfi	Ms, mp	C	Cs	Common mica flakes
C	150 – 200+	10 YR4/4	5 YR 4/6	M3P	Fsil	SAB	Mfi	Ms, mp			Common mica flakes
TFN2 (Typic Epiaquepts/Fluvic Cambisol)											
Ap	0 – 11	7.5 YR 3/3			Fls	Cr	Fr	Ns, np		Cs	Many mica flakes, many large medium roots
Ap2	11 – 35	10 YR 4/4			Fsil	SAB	Sfi	Ss, sp	C	Cs	Many mica flakes, many large medium roots
B1	35 – 44	10 YR 5/2			Fsilcl	SAB	Mfi	Ss, sp		Cs	Common mica flakes, many large medium roots
B2	44 – 70	10 YR 5/3	5 YR 5/6	C2D	Fsil	SAB	Sfi	Ss, sp		Cs	Common mica flakes, common large medium roots
C1	70 – 126	10 YR 5/2	5 YR 3/3	M3P	Fsil	SAB	Sfi	Ss, sp		Dg	Common mica flakes, few large roots
C2	126 – 200+	10 YR 6/2	5 YR 3/3	M3P	L	SAB	Sfi	Ss, sp			Common mica flakes, few large roots
TFN3 (Aquic Udifluvents/Haplic Fluvisol)											
A	0 -13	10 YR 3/3			Fsl	M	Sfi	Ss, sp		Dw	Common mica flakes, many fine medium roots
Ap1	13 -23	10 YR ¾			sl	gr	Fr	ns, Np		Dw	Many mica flakes, many fine medium roots
Ap2	23 – 38	10 YR 5/4			sl	gr	Fr	ns, Np		Cs	Many mica flakes, many fine medium roots
C1	38 – 52	10 YR 3/3	10 R 3/3	M2D	sl	gr	Fr	ns, Np		Cs	Many mica flakes, few medium roots
C2	52 – 69	10 YR 4/6	10 YR 3/3	M2D	sl	gr	Fr	ns, Np		Cs	Many mica flakes, few medium roots
C3	69 – 83	10 YR 3/3			Ls	Sg	L	ns, Np		Cs	Many mica flakes
C4	83 – 200+	10 YR 6/3			S	Sg	L	Ns, Np			Many mica flakes

Keys: Mottle pattern- The first letter denotes abundance (F=few; C=common; M=many); The center number denotes size (1=fine; 2=medium; 3=coarse); The second letter denotes contrast (D=distinct; P- prominent).; structure: Cr=crumbly, VWSAB=very weak sub angular blocky, WSAB=weak sub angular blocky, SAB=sub angular blocky, crumb=crumbly, sg=single grain; Texture: fsil=fine silt loam, sl=sandy loam, ls=loamy sand, fsl=fine sandy loam, fsicl=fine silty clay loam, Consistence: ns=non sticky, np=non plastic, ss=slightly sticky, sp=slightly plastic, fr=friable, sfi=slightly firm; mfi=moderately firm; concretion: c=carbon concretions; boundary: cs=clear smooth; g=gradual; *=all belong to iso-hyperthermic temperature regime.

Table 3a. Physico-Chemical Properties of Elemebiri Soils

Hor.	Depth (cm)	pH		ΔpH	EC (dS/M)	T-N (%)	Org. C (%)	C/N ratio	Avail P (mg/kg)	Exchangeable (cmol/kg)				T E B (cmol/kg)	Ca/Mg ratio	Exchangeable (cmol/kg)		E C E C/ (cmol/kg)	Al Sat (%)	B S (%)	Silt/clay ratio	Textural Classification
		H_2O	$CaCl_2$							Ca^{2+}	Mg^{2+}	K^+	Na^+			Acid	Al					
ELM1 (Aquic Dystrudepts/Fluvic Cambisol)																						
Ap	0-8	5.46	5.25	0.21	0.06	0.25	2.25	9	18	0.74	0.64	1.65	0.09	3.12	1.16	2.5	0.8	5.62	14	61	6.7	Silt loam
Ap2	8-21	5.62	5.36	0.26	0.21	0.11	2.24	20	16	1.26	0.59	0.55	0.09	2.49	2.14	1.5	1.1	3.99	28	62	3.4	Silt Loam
B1	21-34	5.77	5.17	0.6	0.09	0.08	1.52	19	9	0.78	0.43	0.53	0.06	1.8	1.81	2.4	1	4.2	24	43	1.7	Silty clay loam
B2	34-65	5.73	5.15	0.58	0.11	0.09	1.5	17	10	0.76	0.49	1.42	0.07	2.74	1.55	2.0	0.7	4.74	15	58	1.9	Silty clay loam
C1	65-90	6.55	5.37	1.18	0.12	0.08	1.22	15	6	0.75	1.22	0.47	0.07	2.51	0.16	1.8	1	4.31	23	58	7	Silt loam
C2	90-118	5.72	4.94	0.78	0.12	0.04	0.7	18	6	1.2	0.10	0.21	0.08	1.59	12.00	1.8	1	3.39	29	47	6.9	Silt loam
C3	118-150	5.85	5.36	0.49	0.08	0.06	0.71	12	5	1.22	0.16	0.18	0.08	1.64	7.63	2.4	1.8	4.04	46	41	4.9	Silt loam
C4	150-200+	5.86	5.22	0.64	0.23	0.05	1.07	21	3	0.71	0.49	0.72	0.07	1.99	1.45	1.4	1.1	3.39	32	59	2.8	Silt loam
ELEM2 (Typic Epiaquepts/Fluvic Cambisol)																						
Ap	0-11	5.44	5.31	0.09	0.06	0.09	1.03	11	16	1.95	0.09	0.43	0.10	2.57	0.10	1.7	1.2	4.27	28	69	4.1	Silt loam
Ap2	11-19	5.74	5.23	0.51	0.09	0.01	0.21	21	17	0.80	0.09	0.62	0.03	1.54	0.03	0.9	0.6	2.44	25	63	4.6	Silt loam
B1	19-32	6.61	5.37	1.24	0.31	0.02	0.26	13	14	0.80	0.76	0.58	0.07	2.21	0.07	2.1	0.9	4.31	21	52	5.2	Silt loam
B2	32-42	6.04	5.20	0.84	0.01	0.02	0.16	8	10	0.85	0.79	0.66	0.07	2.37	0.07	2.7	0.8	5.07	16	52	4.8	Silt loam
B3	42-57	6.07	5.22	0.85	0.21	0.01	0.11	11	7	0.84	0.13	0.44	0.06	1.47	0.06	2.3	1.3	3.77	34	47	4.1	Silt loam
B4	57-88	5.74	5.20	0.54	0.08	0.02	0.12	6	8	0.90	0.48	0.70	0.08	2.16	0.08	1.5	1.0	3.66	27	65	3.6	Silt loam
C1	88-106	6.15	5.32	0.83	0.06	0.03	0.16	5	6	0.63	0.43	0.18	0.05	1.29	1.47	1.7	0.9	2.99	30	51	4.5	Silt loam
C2	106-190+	6.18	5.17	1.01	0.07	0.03	0.14	5	7	0.85	0.36	0.26	0.04	1.51	2.36	0.7	0.5	2.21	23	73	5.3	Silt loam
ELEM3 (Eutric Udifluvents/Haplic-Fluvic Fluvisol)																						
A	0-18	5.52	5.42	0.10	0.04	0.03	0.84	28	15	0.73	0.45	0.45	0.07	1.70	1.62	1.2	1	2.90	34	66	4.5	Loamy sand
Ap1	18-31	7.00	5.30	1.70	0.07	0.06	0.78	13	18	0.84	0.97	0.58	0.08	2.47	0.87	1.9	1.2	4.37	27	62	6	Loamy sand
Ap2	31-44	6.15	5.31	0.84	0.06	0.04	0.82	21	9	0.72	0.76	0.18	0.06	1.72	0.95	1.2	0.7	2.92	24	65	7	Sandy loam
C1	44-68	5.95	5.64	0.31	0.09	0.02	0.53	27	9	0.72	0.08	0.12	0.07	0.99	9.00	0.5	0.3	1.49	20	76	5	Loamy sand
C2	68-81	5.98	5.30	0.68	0.07	0.04	0.56	14	10	0.56	0.22	0.33	0.03	1.14	2.55	1.0	0.6	2.14	28	59	10	Loamy sand
C3	81-123	5.79	5.19	0.60	0.22	0.07	0.56	8	6	0.87	0.08	0.27	0.08	1.30	10.88	1.8	1.0	3.10	32	53	1.8	Sandy loam
C4	123-160	5.86	5.33	0.53	0.09	0.05	0.59	12	7	1.20	0.43	0.52	0.08	2.23	1.79	2.8	1.9	5.63	34	46	1.8	Sandy loam
C5	160-200+	5.31	5.27	0.04	0.04	0.04	0.57	14	5	1.28	0.74	1.81	0.08	3.91	1.73	2.2	1.0	6.11	16	68	1.3	Sandy loam

Table 3b. Physico-Chemical Properties of Odoni Soils

Hor.	Depth (cm)	pH		ΔpH	EC (dS/M)	T-N (%)	Org. C (%)	C/N ratio	Avail P (mg/kg)	Exchangeable (cmol/kg)				TEB (cmol/kg)	Ca/Mg ratio	Exchange (cmol/kg)		ECEC (cmol/kg)	Al Sat (%)	BS (%)	Silt/clay ratio	Textural Classification
		H_2O	$CaCl_2$							Ca^{2+}	Mg^{2+}	K^+	Na^+									
ODN1 (Humic Dystrudepts/Fluvic Cambisol)																						
Ap	0-23	5.76	5.33	0.43	0.12	0.05	1.07	21.	12	0.75	0.99	0.24	0.07	2.05	0.76	2.2	1.4	4.25	33	55	5.4	Silt loam
Ap2	23-30	5.75	5.17	0.42	0.19	0.05	0.58	12	15	1.25	0.58	0.53	0.09	2.45	2.16	1.9	1.0	4.35	23	63	5	Silt loam
B1	30-63	6.01	5.27	0.74	0.11	0.04	0.41	10	8	0.75	0.20	0.43	0.07	1.45	3.75	2.1	1.6	3.55	45	50	3.9	Silt loam
B2	63-117	6.32	5.30	1.02	0.00	0.02	0.2	10	7	0.85	0.93	1.12	0.09	2.99	0.91	1.1	0.7	4.09	17	77	8.8	Silt loam
B3	117-160	5.33	5.17	0.16	0.16	0.01	0.1	10	9	0.91	0.43	0.52	0.09	1.95	2.12	2.8	1.8	4.75	38	49	2.9	Silt loam
C	160-200+	6.48	5.72	0.76	0.17	0.01	0.12	12	3	0.72	0.15	0.17	0.03	1.07	4.80	1.4	0.8	2.47	32	48	3.3	Silt loam
ODN2 (Typic Epiaquepts/Fluvic Cambisol)																						
Ap	0-10	5.64	5.22	0.42	0.12	0.09	1.32	15	16	0.74	0.86	0.10	0.07	1.77	0.86	2.2	1.6	3.97	40	45	3.2	Silt loam
Ah	10-21	6.70	5.32	1.38	0.14	0.21	2.13	10	16	0.79	0.46	0.48	0.08	1.81	1.72	2.9	1.9	4.71	40	38	4.4	Silt loam
B1	21-37	5.38	5.18	0.20	0.14	0.04	0.2	5	8	0.7	0.28	0.42	0.07	1.47	2.50	1.5	0.9	2.97	30	49	3.9	Silt loam
B2	37-46	6.11	5.30	0.81	0.06	0.03	0.37	12	4	0.78	0.89	0.15	0.08	1.9	0.88	1.8	0.9	3.7	24	51	3.9	Silt loam
BC	46-79	6.41	6.19	0.22	0.07	0.06	0.67	11	2	0.83	0.54	0.44	0.05	1.86	1.54	6.2	3.6	8.06	45	23	4.4	Silt loam
C1	79-149	6.19	5.38	0.81	0.08	0.06	0.73	12	3	0.75	0.38	0.82	0.07	2.02	1.97	1.4	0.7	3.42	20	59	2.8	Loam
C2	149-200+	6.37	5.27	1.10	0.20	0.06	0.66	11	2	0.74	0.45	0.29	0.07	1.55	1.64	1.9	1	3.45	29	45	2.7	Loam
ODN3 (Fluvaquentic Epiaquepts/Fluvi Cambisol)																						
A	0-5	5.67	5.37	0.30	0.67	0.2	2.33	12	19	1.95	0.70	0.61	0.13	3.39	2.79	1.6	0.8	4.99	16	68	3.5	Silt loam
Ap1	5-11	6.45	5.51	0.94	0.10	0.17	1.97	12	22	0.69	0.45	0.18	0.04	1.36	1.53	2.3	1.5	3.66	41	37	5.4	Silt loam
Ap2	11-25	5.97	5.18	0.79	0.04	0.07	0.84	12	14	1.2	0.32	0.68	0.09	2.29	3.75	1.7	1	3.99	25	57	3.4	Silt loam
B1	25-41	6.07	5.31	0.76	0.00	0.03	0.31	10	14	0.75	0.47	0.65	0.07	1.94	1.60	2.0	1.2	3.94	30	49	2.4	Silt loam
B2	41-48	6.45	5.70	0.75	0.00	0.09	0.99	11	3	0.73	0.40	1.40	0.07	2.6	1.83	2.0	1.2	4.6	26	57	1.8	Silty clay loam
B3	48-56	5.91	5.36	0.55	0.00	0.03	0.31	10	1	1.22	0.92	2.13	0.07	4.34	1.33	2.5	1.6	6.84	23	63	1.7	Silty clay loam
C1	56-122	6.20	5.27	0.93	0.05	0.06	0.64	11	1	1.2	0.39	0.58	0.08	2.25	3.08	3.4	2	5.65	35	40	2.2	Loam
C2	122-200+	6.62	5.32	1.30	0.25	0.08	0.89	11	5	0.73	0.39	0.77	0.08	1.97	1.87	2.1	1.3	4.07	32	48	2.5	Loam

Table 3c. Physico-Chemical Properties of Trofani Soils

Hor.	Depth (cm)	pH		ΔpH	EC (dS/M)	T-N (%)	Org. C (%)	C / N ratio	Avail P (mg/kg)	Exchangeable (cmol/kg)				TEB (cmol/kg)	Ca / Mg ratio	Exchange (cmol/kg)		ECEC (cmol/kg)	Al Sat (%)	BS (%)	Silt/clay ratio	Textural Classification
		H_2O	$CaCl_2$							Ca^{2+}	Mg^{2+}	K^+	Na^+			Acid	Al					
TFN1 (Aquic Dystrudepts/Fluvic Cambisol)																						
Ap	0-14	5.64	5.12	0.52	0.09	0.13	1.6	12	12	0.75	0.12	0.15	0.07	1.09	0.07	1.8	1	2.89	35	38	3.2	Silt loam
A	14-31	5.75	5.25	0.50	0.07	0.06	0.45	8	8	0.78	0.42	0.65	0.07	1.92	0.07	2.1	1.4	3.62	39	53	3.6	Silt loam
B1	31-55	5.88	5.14	0.74	0.10	0.03	0.24	8	4	0.78	0.98	0.26	0.05	2.07	0.05	2.3	1.5	4.37	34	47	4.5	Silt loam
B2	55-140	5.95	5.39	0.56	0.00	0.02	0.21	11	11	0.75	0.32	0.62	0.07	1.76	0.07	1.9	0.9	3.66	25	48	3.9	Silt loam
B3	140-150	5.86	5.29	0.57	0.11	0.04	0.68	17	5	0.56	0.22	0.16	0.03	0.97	0.03	5.4	2.4	6.37	38	15	2.1	Silty clay loam
C	150-200+	5.30	5.09	0.21	0.04	0.04	1.04	26	16	0.77	0.20	0.61	0.07	1.65	0.07	2.0	0.8	4.45	18	37	3.1	Silt loam
TFN2 (Typic Epiaquepts/Fluvic Cambisol)																						
Ap	0-11	6.16	5.35	0.81	0.01	0.06	1.28	21	17	0.75	0.12	0.15	0.07	1.09	0.07	1.8	1	2.89	35	38	4.3	Loamy sand
A2p	11-35	6.15	5.06	1.09	0.09	0.05	0.59	12	10	1.83	0.89	0.14	0.08	2.91	0.08	3.3	1.9	6.21	31	47	2.4	Silt loam
B1	35-44	5.98	5.17	0.81	0.01	0.03	0.35	12	15	1.22	0.32	0.53	0.08	2.15	0.08	2.6	1.1	4.75	23	45	2	Silty clay loam
B2	44-70	6.80	5.25	1.55	0.00	0.03	0.31	10	5	0.89	0.40	1.88	0.07	3.24	0.07	1.8	0.7	5.04	14	64	2.6	Silt loam
C1	70-126	6.40	4.90	1.50	0.00	0.02	0.19	10	15	0.78	0.66	0.28	0.07	1.79	0.07	1.0	0.6	2.79	22	64	5.3	Silt loam
C2	126-200+	6.15	5.06	1.09	0.03	0.02	0.21	11	2	1.83	0.48	0.28	0.05	2.64	0.05	0.8	0.5	3.44	15	77	4.9	Loam
TFN3 (Aquic Udifluvents/Haplic Fluvisol)																						
A	0-13	5.74	5.24	0.50	0.00	0.10	1.20	12	15	1.24	0.93	0.46	0.09	2.72	0.09	1.8	1.2	4.52	27	60	6.3	Sandy loam
Ap1	13-23	5.98	5.16	0.82	0.05	0.06	0.72	12	10	0.8	0.68	0.51	0.07	2.06	0.07	1.6	0.9	3.66	26	56	14	Sandy loam
Ap2	23-38	5.55	4.98	0.57	0.00	0.05	0.55	11	3	0.75	0.34	0.94	0.07	2.1	0.07	1.7	1	3.8	26	55	3.6	Sandy loam
C1	38-52	6.06	5.28	0.78	0.00	0.03	0.30	10	9	0.74	0.34	0.50	0.07	1.65	0.07	1.4	0.7	3.05	23	54	3.1	Sandy loam
C2	52-69	5.98	5.33	0.65	0.00	0.06	0.68	11	5	0.95	1.01	0.63	0.08	2.67	0.08	2.0	1	4.67	21	57	3.6	Sandy loam
C3	69-83	6.11	5.15	0.96	0.13	0.03	0.32	11	4	0.78	0.06	0.19	0.07	1.1	0.07	4.6	2.2	5.7	39	19	1.4	Sandy loam
C4	83-200+	5.79	5.28	0.51	0.00	0.01	0.08	8	10	0.74	0.53	0.88	0.07	2.22	0.07	1.0	0.8	3.92	20	57	8	Sand

However, in ELM3 (Table 2) and TFN3 (Table 2), mottling was observed only in the 18-31 cm depth of ELM and the 38-69 cm depth of TFN3 Since there was no perched water table below the 18-31cm depth of ELM3 and the 38-69 cm depth of TFN3 the mottled layers and no mottling above and below these layers, the mottling in these layers was attributed to the parent materials of the specific layers which indicated heterogeneity in parent materials of ELM3 and TFN3. The two pedons located on alluvial soils formed on the channels of present active rivers. In spite of the fact that ELM3 and TFN3 soils were formed from recent alluvial materials deposited in the middle of the actively flowing Niger River and Forcados river, respectively, drainage was near perfect. However, even in the other pedons, no saturation zone was found in any of the profiles during the dry season.

In ODN3, common, medium, distinct, reddish brown (5 YR 5/3), light reddish brown (5 YR 6/4), gray (5 YR 6/1), and reddish gray (5 YR 5/2) mottles occurred on the second, third, fourth and fifth layers, respectively. Mottle colours of chroma of 2 or less and hues of 5YR in some of the layers and even in the colour matrix of one of the ODN3 horizons suggested that the soils have aquic moisture regime during part of the year and gleization is part of the soil forming process. These observations agreed with the results recorded for Onwu River floodplain soils in Cross River State, Nigeria (Akpan-Idiok & Ogbaji, 2013) and inland bottom Basement complex soils in sub-humid southwestern Nigeria (Babalola et al., 2011). Variation in the colour matrix of most of the profiles was traced to differences in chemical and mineralogical composition, soil organic matter contents, textures, parent materials, topographic positions and most importantly, moisture regime or waterlogging, and redox reaction in the soil (Dengiz et al., 2012; Abate et al., 2014). The ODN3 soil was subject to longer period of flooding each year by the seasonal floods than ODN1 and ODN2. The change in wet consistence along the profiles with depth was attributed to change in particle size distribution of the soil, which agreed with the findings of Alemayehu et al. (2014) for southwestern lowland soils of Ethiopia.

The dark surface soil colour of Trofani soils was traced to the effect of organic matter as noted previously by Dengiz et al. (2012) and Abate et al. (2014), while the occurrence of black concretions at the fifth layer of TFN1 and the second layer of TFN2 indicated previous anthropogenic activities in the area. Structural development of ELM3 and TFN3 was very weak due to the annual enrichment of the profiles with new deposits which could be considered recent. The horizon succession of ELM3 was A-Ap1-Ap2-C1-C2-C3-C4-C5 while that of TFN3 was in the order Ap1-Ap2-C1-C2-C3-C4 which defined them as A-C. This means the profile has no textural B horizon and is therefore low in pedogenetic development, which qualified it as very young. Also, the presence of mica flakes in all the profiles indicated the presence of weatherable minerals, implying the embryonic nature of the soil.

Physical Properties

Soil physical and chemical properties usually vary as a result of dynamic interactions among environmental factors such as climate, parent materials, topography and land cover/land use. The distribution of sand, silt and clay in the various horizons of the SMUs are presented in figures 2, 3 and 4. Silt-sized particles dominated ELM1, ELM2, ODN1, ODN2, ODN3, TFN1 and TFN2. The textural classes of the soils were dominantly silt loam followed by silty clay loam and loam except ELM3 and TFN3, dominated by loamy sand and sandy loam. According to Akpan-Idiok & Ogbaji (2013), soil texture is the single most important characteristic which control water infiltration, influence soil chemical reactions, potential erosion factor and soil nutrient availability. Soil-plants relationships, to a large extent are influenced by soil texture. Fine textured soils for instance, are known for their good water retention properties, facilitate soil chemical reactions, store and release more nutrient elements and increase organic matter content.

Abua (2012), associated high silt fraction of soil, with good aggregation and high absorptive capacity. He reported that soils with high sand fraction exceeding 70% may mean silt content is below 15% and such soil would have weak surface aggregation. The soil may lack adsorptive capacity for basic plant nutrients and may be susceptible to erosion menace while silt fraction greater than 15% for both top and sub soils indicated that the soils have strong surface aggregation and may not be vulnerable to erosion hazard. In the ELM1 and ELM2 SMUs, silt content of the surface and subsurface layers are greater than 50% which means the soils have high adsorptive capacity, strong surface aggregation and may not be vulnerable to erosion hazard (Fig. 2). Silt and clay contents were low in ELM3 SMU located at the centre of the present actively flowing lower Niger River implying that coarse materials carried by the Niger River current were deposited there. Textural class distribution in the profiles showed silt loam as the dominant textural class in the ELM1 and ELM2 and loamy sand and sandy loam in ELM3. The dominance of loam in the textural class of most of the soils indicated good infiltration rate and medium water holding capacity to sustain the commonly cultivated crops. In the ELM3 and TFN3 soils however, sand dominated the texture which is an indication of observable high infiltration rate and low water holding capacity of the soils, suggesting the likelihood of whereby resulting into moisture stress as reported by Senjobi (2007) and Senjobi et al. (2016). During the time of soil sampling between January and March, farmers were seen pumping water from the Lower Niger River and Forcados River to water their crops at Elemebiri and Trofani, respectively.

A close look at the particle size composition of Odoni soils showed a regular distribution of textural classes of soil in all the SMUs. For instance, surface and subsurface soil textures of ODN1 were silt loam as well as the surface textures of ODN2 and ODN3 (Fig. 2). Of the seven horizons delineated in ODN 2, the top five layers were silt loam while the remaining two bottom layers were loam. Of the eight horizons delineated in ODN3, the first four horizons from top were silt loam, the two horizons following them, silty clay loam and the remaining two, loam. The soils did not show so much variation, possibly because the alluvial deposits came from similar sources and soil development was still in the early stage.

The textural classes of TFN1and TFN3 were fairly uniform. This can be attributed to the fact that the deposits were either of the same source or similar, and soil development was still in the early stage. On the other hand, variation in textural classification down the profile was noticeable in TFN2 (Fig. 2) which may be attributed to differences in parent material sources and texture.

The dominance of sand in ELM3 and TFN3 (Fig. 2) indicated that the SMUs have high infiltration rate and low water holding capacity with possibility of moisture stress during dry months (Senjobi, 2007; Senjobi et al., 2016). The clay distribution within ELM1, ELM2, ODN1, ODN2, ODN3, TFN1 and TFN2 SMUs was irregular. Lawal et al. (2013) reported irregular distribution of clay within the subsoil of three pedons, characteristic of cambic horizon. Though the distribution of silt/clay ratio was also irregular with depth, silt/clay ratios generally increased with increase in silt content and vice versa (Tables 3a, b, c).

Alemayehu et al. (2014), reported increased silt/clay ratio with depth of profiles that followed opposite pattern of variation with clay particles. In the Elemebiri SMUs, the distribution of silt/clay ratio was irregular with depth but silt/clay ratio increased with increase in silt content and vice versa. Higher silt/clay ratio in the surface layers indicated recent annual enrichment of the surface through deposition by the annual floods. In this case, the levee crest, levee slope and soils on the present active Niger River of Elemebiri were at the early stage of development.

It has been reported (Egbuchua & Ojobor, 2011) that "old" parent materials usually have silt/clay ratio below 0.15 while silt/clay ratio of above 0.15 are indicative of young" parent materials. Lawal et al. (2013) recorded silt/clay ratio of <1.00 in Southern Guinea Savanna soils in Nigeria and concluded that the soils have undergone ferralitic pedogenesis. All the SMUs recorded silt/clay ratios far above unity confirming that the soils are young with weatherable minerals and have not gone through ferralitic pedogenesis.

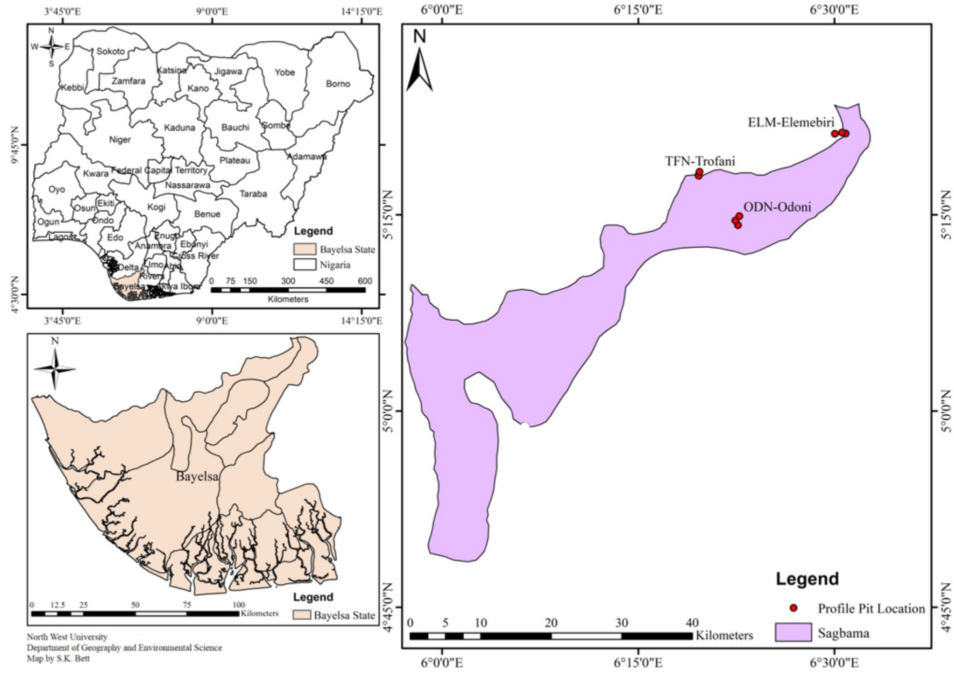

Fig. 1. Map of Bayelsa State Showing the Sampling Points

Chemical Properties

The SMUs were moderately acidic to neutral, pH ranging from 5.31 to 7.00 (H_2O) and 4.94-5.64 ($CaCl_2$) for Elemebiri soils, 5.33-6.70 (H_2O) and 5.17-6.19 ($CaCl_2$) for Odoni soils and 5.30-6.80 (H_2O) and 4.90-5.39 ($CaCl_2$) for Trofani soils (Fig. 3). Available P ranged from 3-18 mgkg^{-1} in Elemebiri soils, 5-21 mgkg^{-1} in Odoni soils and 3-17 mgkg-1 in the Trofani soils while exchangeable K varied from 0.18-1.81 cmolkg^{-1} in Elemebiri, 0.10-2.13 cmolkg^{-1} in Odoni and 0.14-1.88 cmolkg^{-1} in the Trofani soils. The pH of the soils generally increased with soil depth due to less H^+ ions released from organic matter decomposition as organic matter decreased irregularly with increase in depth (Buol, 2003). Wong et al. (2001) reported pH of 6.0 to 7.0 as the optimum pH for most agricultural crops while FAO (2006) and Brady & Weil (2008) gave 5.5 to 7.0 as the preferred range for most crops. Among the SMUs, the surface layers of ELM1 and ELM2 fall below the FAO preferred pH range. This is an indication that the SMUs need some form of soil amendments. Khan et al. (2012) attributed rise in soil pH with depth to ferrolysis which is acidification of topsoil occasioned by continual displacement of bases by ferrous ion during the reduction phase accompanying annual flooding. The study area is prone to high rainfall and flooding therefore, there is possibility of ferrolysis. Usually, ΔpH value is used to estimate the presence of negatively charged clay colloids in soils (Alemayehu et al., 2014). Positive ΔpH values were obtained for all the soils indicating that the soils were all negatively charged. The EC values for all the profile was below unity indicating that the soils were not saline.

Generally, organic carbon and indeed organic matter levels decreased irregularly with soil depth which agreed with the reports of previous authors in Nigeria (Idoga & Azagaku, 2005; Atofarati et al., 2012) and in Ethiopia (Abate et al., 2014; Alemayehu et al., 2014). Khan et al. (2012) also reported organic C decrease with soil depth for Bangladeshi soils and low organic C content which was attributed to rapid decomposition of organic matter under hyperthermic temperature regime. For

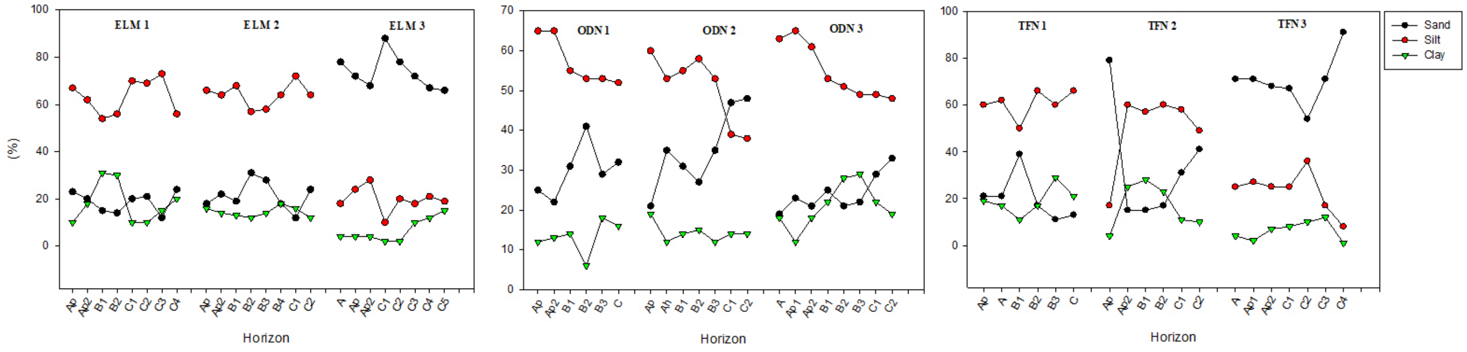

Fig. 2. scattered plot showing distribution of sand, silt and clay across the three study locations

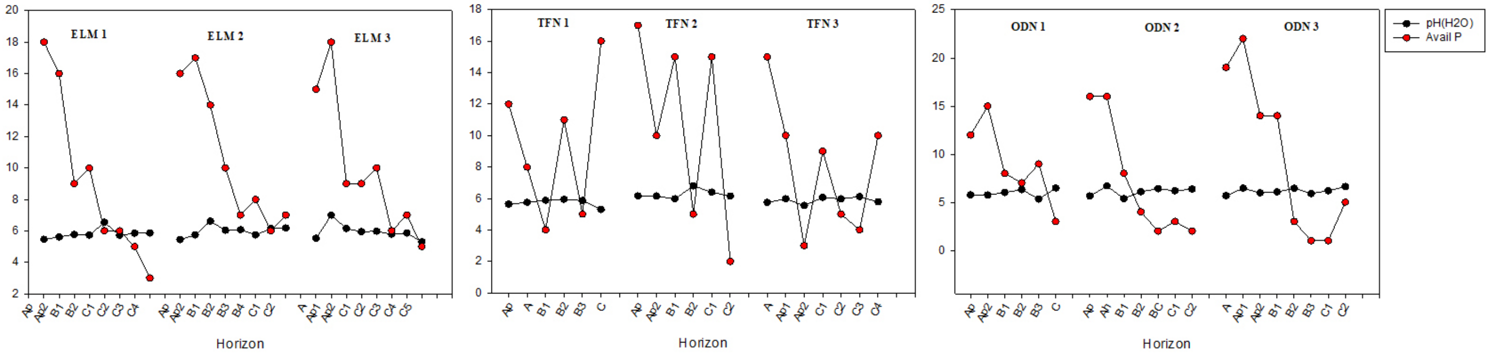

Fig. 3. Scattered plot showing pH status and available phosphorus across the three study locations

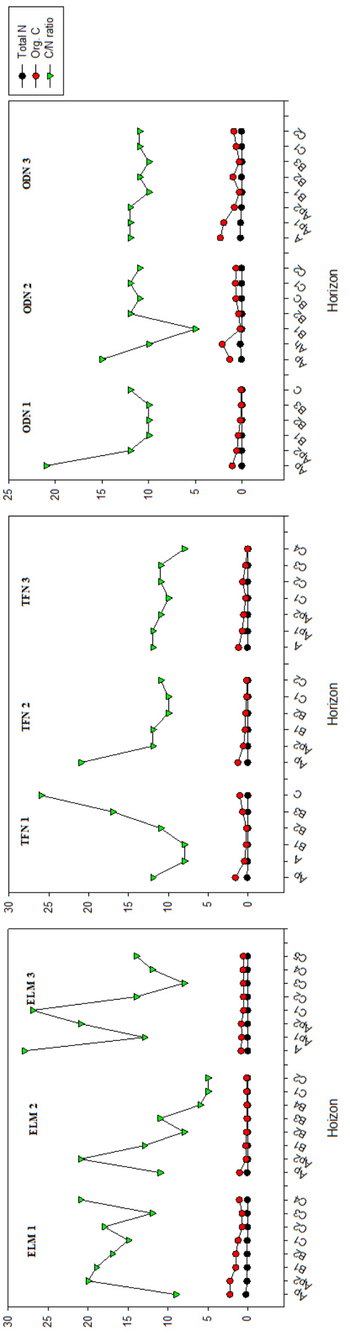

Fig. 4. Scattered plot showing distribution of compositional distribution of total N, organic C and C:N ratio across the three study locations

the soils under consideration, low organic matter concentration was attributed to low biomass return to the soils owing to short fallow periods coupled with the cultural practice of bush burning which destroys organic materials. It needs to be noted that organic matter mineralization rate in the soils is high due to high temperature and heavy rainfall. The SMUs belong to the iso-hyperthermic soil temperature regime. Low N values was traced to high rate of organic matter decomposition and mineralization as well as leaching, coupled with water saturation and drying which is known to favour N loss through nitrification-denitrification processes (Brady & Weil, 2008). Hartz (2007) reported that soils with less than 0.07% total N have limited N mineralization potential, whereas those having values greater than 0.15% would be expected to mineralize sufficient amount of N during the succeeding crop cycle. Based on this, the surface layers of ELM1, ELM2, ODN2, ODN3, TFN1, and TFN3 (Fig. 4) are likely to have reasonable mineralization potential while the mineralization potential of ELM3, ODN1 and TFN2 was low. Higher P values were recorded generally in the surface layers revealing the close relationship between organic matter and soil P. Based on the categorisation of FAO (2006), it is obvious that K in most layers of the pedons was medium to very high.

Cation ratios are helpful in identifying soil structural problems. In the SMUs, Ca^{2+}/Mg^{2+} ratio of most of the layers was above unity (Tables 3). Khan et al. (2012) reported Ca^{2+}/Mg^{2+} ratios of less than unity in Bangladeshi soils, attributing this development to Ca^{2+} loss due to gleization. Buol (2003) reported that Ca^{2+}/Mg^{2+} ratio in soils decreases with increasing maturity. The low Ca^{2+}/Mg^{2+} ratios recorded in the SMUs was rather ascribed to the inherently low concentration of ferromagnesian minerals that supply Ca and possibly loss of Ca by gleization as noted previously by Khan et al. (2012). Low exchangeable bases in soils (Ca, Mg, K and Na) have been attributed to acidifying properties of organic matter, high aluminium concentration and leaching loss of exchangeable bases (Havlin et al., 2004). The low exchangeable Ca and Mg in these soils was attributed to the inherently low concentration of ferromagnesian minerals, low nutrient retentive capacity, high exchangeable Al and leaching losses due to the high rainfall.

The exchange acidity of 45% of the soils was 2.0 cmolkg-1 and above suggesting that 45% of the soils were slightly to strongly acidic (Ernest & Onweremadu, 2016), Odoni soils having higher total exchange acidity.

Classification of the Soils

Because there is little or no difference in soil temperature between the rainy season and the dry season at a depth of 50 cm. The ELM3 and TFN3 soils had weak profile development owing to the yearly deposition of fresh alluvium and the concentration of weatherable minerals was high. The pedons has no diagnostic horizon except ochric epipedon which qualified them to be placed into the Entisols soil order. The ELM1, ELM22, ODN1, ODN2, ODN3, TFN1 and TFN2 soils substantial evidence of subsoil horizon differentiation with change in colour and structure of the pedons but the absence of illuviated clay and organic carbon with increasing depth qualify them to be placed in the Inceptisols soil order. The following classifications were made according to the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base (FAO/ISRIC, 2006).

The ELM1 soil was placed in the Udepts suborder and Dystruderpts Great Group because it has a low base saturation between 25 and 75 cm depth. At the subgroup level, it was placed under Aquic Dystrudepts because of ground water influence at 118 cm and below and Fluvic Cambisols (Eutric, Siltic) in the WBR system. The ELM2 soil was included in the Aquepts suborder due to observed ground water and in the Epiaquepts Great Group because there were gleyic properties down the profile, no plinthite within 100 cm depth, and exchangeable sodium percentage (ESP) was far less than 15%. As the percent organic carbon content from 32-42 cm layer was less than 0.2, decreasing irregularly down the profile, it was grouped into Typic Epiaquepts and Fluvic Cambisol (Eutric, Siltic) in the World Reference Base system. The ELM3 soil is located at the centre of the channel of the Lower Niger River which was subject to the annual floods, and was placed in the Fluvents Suborder and into the Great Group Udifluvent because it was located in the humid tropics and has Udic moisture regime. Due to the high base saturation of the upper layers of the profile, it was classified as Eutric Udifluvents at the Sub Group level. The equivalent class in the WRB was Haplic-Fluvic Fluvisol (Eutric, Siltic).

The ODN1 soil was placed in the Udepts Suborder because underground water influence was below 100 cm and the exchangeable sodium percentage was far below 15%. Since the soil has base saturation of less than 60% in a horizon between 25 and 75 cm, it was classified into the Dystrudepts Great Group and into the Humic Dystrudepts Subgroup because it has base saturation (by sum of cations) of more than 35% at a depth of 125cm from the top of the cambic horizon. The corresponding RSG in the WRB system was Fluvic Cambisols (Eutric, Siltic). The ODN2 soil was placed in Aquepts Suborder because the surface first three horizons had chroma of 2. Due to water saturation of the profile between the surface and below 200 cm depth, it was placed in the Epiaquepts Great Group and into the Sub Group, Typic Epiaquepts because the profile has Hue of 7.5YR. The RSG for ODN2 in the WRB system was Fluvic Cambisol (Dystric, Siltic). The ODN3 was placed into the Suborder, Aquepts due to the occurrence of redoximorphic features from the surface horizon. The Great Group, Epiaquents was given because the ground water fluctuates between surface and below 200 cm at certain periods of the year while the Subgroup, Fluvaquentic Epiaquepts was given due to the fact that the pedon was most times flooded by the seasonal floods and organic carbon decreases irregularly down the profile. The equivalent in the WRB system was Fluvic Cambisol (Dystric, Siltic).

The TFN1 soil was under Udic moisture regime with ground water influence below 140 cm depth and was placed in the Udepts Suborder. The Great Group Dystrudepts was given because base saturation was below 60% all through the horizons while the Subgroup Aquic Dystrudepts was given due to redoximorphic features in the bottom layers of the profile. Fluvic Cambisol (Dystric, Siltic) was the corresponding RSG in the WRB system. The Suborder Aquepts was given to TFN2 because the ground water was near the surface at sometimes during the year and the Great group Epiaquepts given because the ground water fluctuates between near the surface to below 200 cm depth. The Subgroup Typic Epiaquepts was applied because of the 10YR Hue and the low chroma (2) which indicated long periods of water saturation of the affected horizons. The equivalent RSG in the WRB system was Fluvic Cambisol (Eutric, Siltic). In TFN3, the Suborder Fluvents was given due to the fact that the profile was located on the channel of the present active Forcados River subject to seasonal flooding while the Great Group, Udifluvents was given because the moisture regime was udic. The pedon was placed in the Subgroup, Aquic Udifluvents because the pedon was flooded by the flowing seasonal flood waters of Forcados River yearly for more than 30 consecutive days. In the WRB system, the corresponding RSG was Haplic Fluvisol (Arenic, Greyic).

Conclusion

The floodplain soils of the Lower Niger River and the main tributaries (Nun and Forcados) showed some degree of differences in morphological, physical, chemical and mineralogical characteristics, the source of parent materials and degree of hydromorphism, being the major factors moulding morphogenesis. Parent materials were of mixed origin and the soils were at an initial stage of development. Seasonal inundation by the flood water and dryness in the dry season set the stage for alternate oxidation and reduction, providing the most distinguishing feature of the pedochemical environment. Subsurface grayization was a notable morphometric feature and gleization, a major soil forming process. Flooding, wetness and soil fertility are major constraints to agricultural intensification and must be addressed.

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