Environ Res Tec, Vol. 5, Issue. 1, pp. 72–83, March 2022

Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://doi.org/10.35208/ert.973270

Environmental Research & Technology

Research Article

Morphogenesis, physico-chemical properties, mineralogical composition and nature of parent materials of some alluvial soils of the Lower Niger River plain, Nigeria

Achimota DICKSON[1], Joseph ARULEBA[2], Joseph Oyinbrakemi TATE[*1]

[1]*Department of Soil Science, Niger Delta University Faculty of Agriculture, Yenagoa, Bayelsa State, Nigeria*
[2]*Department of Soil Science, Ekiti State University, Ado Ekiti, Ekiti State, Nigeria*

ARTICLE INFO

Article history
Received: 13 August 2021
Revised: 08 January 2022
Accepted: 31 January 2022

Key words:
Floodplain soils; Lower niger river; Mineralogical composition; Morphogenesis; Soil characteristics

ABSTRACT

Nine pedons of alluvial origin in the Lower Niger River floodplains of Nigeria were examined for morphogenesis, physicochemical properties, mineralogical composition, and heterogeneity of the parent materials. The soils were stratified with redoximorphic features observed in the different layers reaching A-horizon with subsurface grayization. Soils that received annual alluvial enrichment were found to be structurally weak while others were moderately strong. Soil characteristics showed varying degrees of heterogeneity with source of parent materials and degrees of hydromorphism, moulding morphogenesis and gleization as major soil-forming processes. Silt loam was the predominant soil texture except ELM3 and TFN3 dominated by sandy loam and loamy sand textures. Soils were strongly acid to neutral [pH (H_2O), 4.94–7.00], having very low to medium organic matter (0.13–4.02 %), and low to very high K (0.1–2.13 cmol kg^{-1}). Quartz dominated the identified mineral phases followed by kaolinite, indicating the dominance of low activity clays and low ferromagnesian minerals presence. The presence of several K-bearing minerals in the pedons (micas and feldspars) suggest that the K pool could naturally be replenished. Textural diversity between the different SMUs is ascribed to different sources of the water-borne sediments and the flow rate of the floodwater at the time of deposition of the parent materials. Organic carbon distribution patterns indicated stratification and heterogeneity of parent materials. Wetness, flooding, and soil chemical and physical fertility were major constraints to increased and sustainable crop production in the Lower Niger River floodplain soils.

Cite this article as: Dickson A, Aruleba J, Tate JO. Morphogenesis, physico-chemical properties, mineralogical composition and nature of parent materials of some alluvial soils of the Lower Niger River plain, Nigeria. Environ Res Tec 2022;5:1:72–83.

INTRODUCTION

Floodplain soils, worldwide, are very useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants [1]. The agricultural potentials of alluvial soils however, have not been fully exploited because of lack of understanding of their physical and chemical properties and the changes they undergo under intensive cultivation [2]. For instance, greyish colouration at lower depths have been associated with ground water influence or poor drainage [3, 4] while [5] associated clear and smooth horizon boundaries with some diffuse, wavy,

***Corresponding author.**
*E-mail address: j.o.tate@ndu.edu.ng

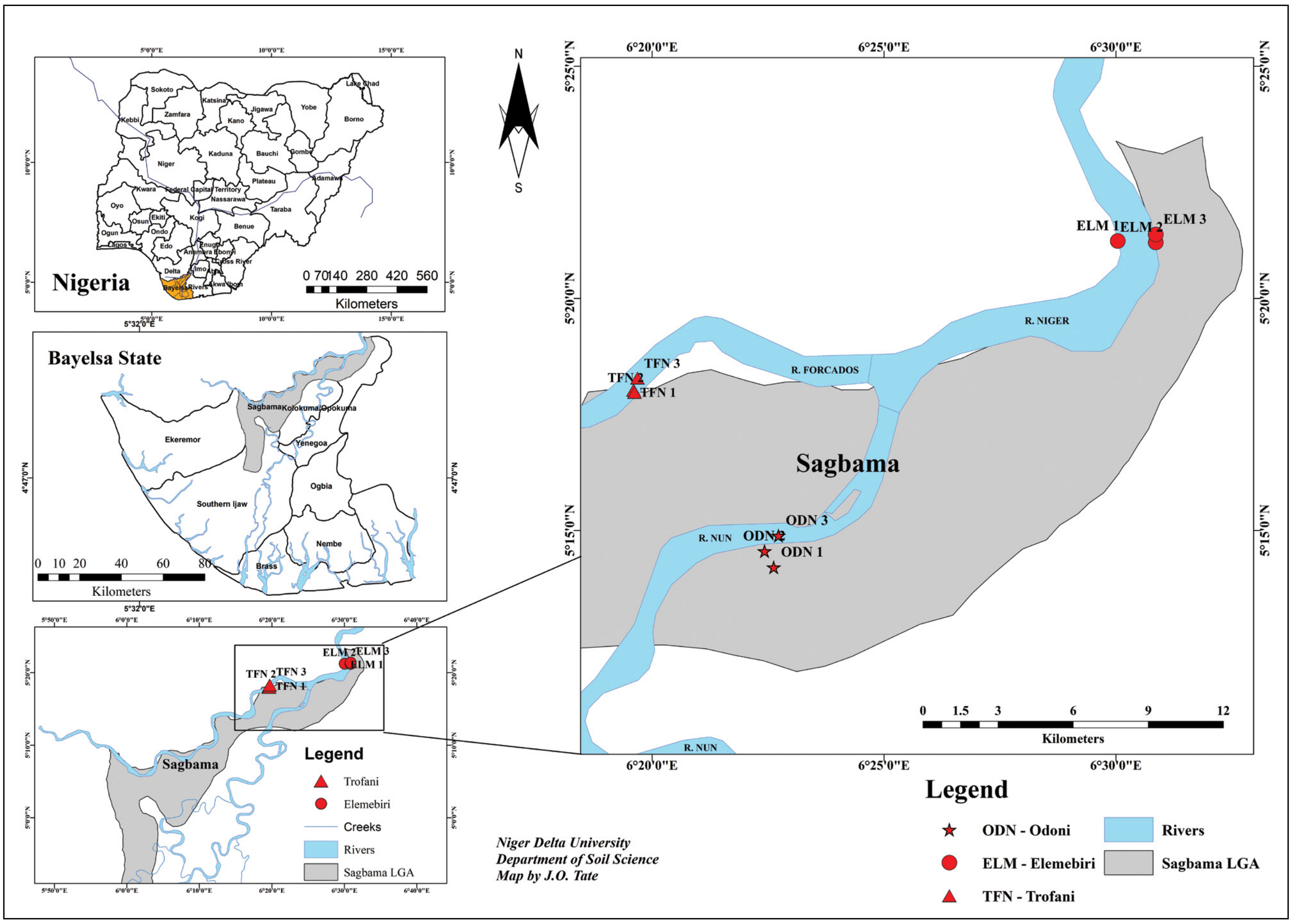

Figure 1. Map showing soil mapping units for the study.

and gradual boundaries to recentness of the soils and young soil development or rejuvenation processes. Two dominant factors appeared to condition kaolinization process under tropical conditions which included composition of the soil solution in the weathering environment and mineralogical composition of the weathering soil or parent rock. However, warm soil temperatures are believed to cause marked dissociation of soil water leading to a build-up of hydrogen ions or lowering of the pH of the soil solution. Under such condition, hydrolytic or H-weathering of silicates to kaolinite progresses rapidly [6]. Texture, organic carbon distribution and clay mineralogy are features commonly used as pointers to the homogeneity or otherwise of the parent materials. Again, the very fine sand and fine sand proportions are used to indicate lithologic discontinuities. Though, it is believed that the floodplain soils of Bayelsa state have high agricultural potentials, current information and knowledge on the dominant soil forming processes, soil characteristics including mineralogical composition, and the homogeneity of parent materials or otherwise are inadequate. For instance, [7] characterization and classification of alluvial soils of the Nun River floodplains did not supply information on the morphogenesis and/or mineralogical status of Bayelsa State soils. Similarly, [8] classification of Ogochie River floodplain soils in Imo State, Nigeria did not provide sufficient morphogenetic information that could be resourceful as an indicator for proper policy formulation by government. Hence, the efficient management of the soils for increase and sustainable crop production is constrained. The situation is further exacerbated by smallholder farmers' poor management practice of low to sub-optimal use of fertilizer inputs [9–11] that neither mitigate the nutrient mining process nor adequately guarantee the restoration of the fertility status [12]. With the present drive of the world towards food security, the state cannot be left behind and 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. The aim of this study, therefore, is to examine the morphogenetic features, physico-chemical, mineralogical properties and nature of the parent materials of soils of some 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

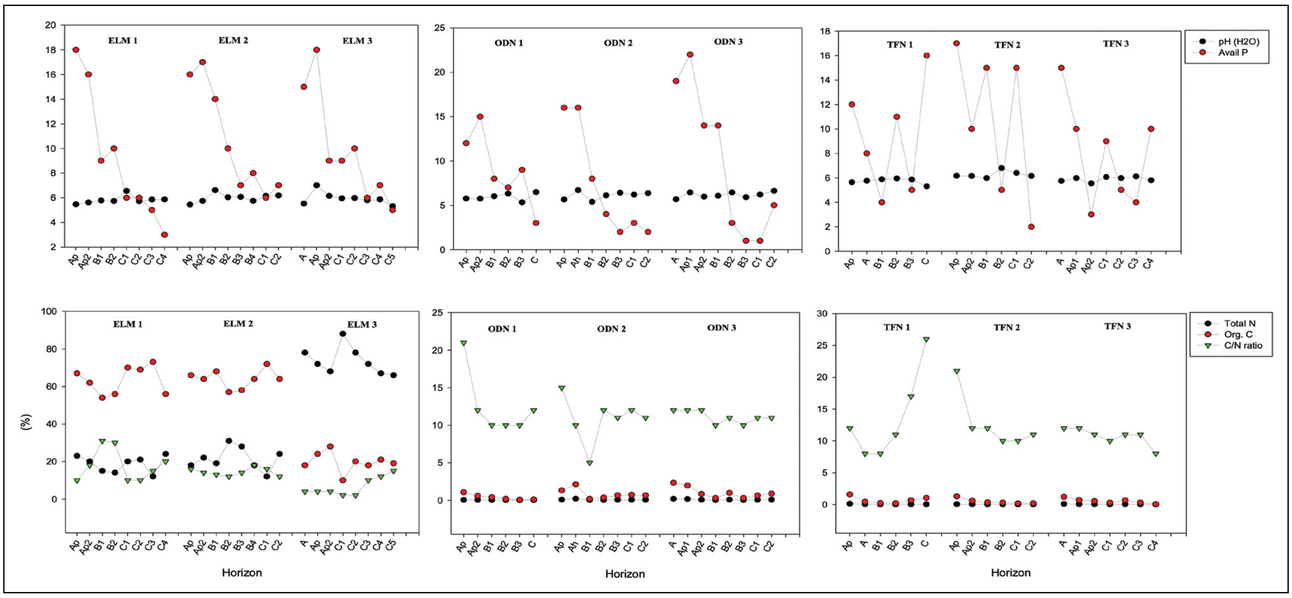

Figure 2. Scattered plot showing the distribution of soil pH, Available P, Total N, Organic C and C/N ratio of Elemebiri, Odoni and Trofani soils.

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 (Figure 1) were chosen for the study due to the proposed agricultural intensification.

Soil Sampling and Analyses

Following a detailed soil survey conducted on agricultural lands from Elemebiri (ELM), Odoni (ODN) and Trofani (TFN) using rigid grids, the SMUs were examined for morphogenetic features, physico-chemical properties, mineralogical composition and heterogeneity of parent materials. 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, representing levee crest, levee slope and floodplain, soil profiles described following the procedures prescribed by the USDA Soil Taxonomy [13] 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. The soil samples collected were air-dried, crushed and sieved to pass through a 2 mm mesh. Soil analyses were carried out 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 [14] method, popularly known as hydrometer method. Soil pH both in water and CaCl2 (1:2 ratio) was determined using glass electrode pH meter and electrical conductivity determined using conductivity meter [15]. Organic carbon was determined using the modified dichromate oxidation method of Walkley-Black as described by [15] 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 [16] and available P by Bray P-1 method [17]. Exchangeable acidity was extracted with 1M KCl and determined by titration with NaOH solution using phenolphthalein indicator [18] and exchangeable Al with 0.01 M HCl [19]. Exchangeable cations were extracted with neutral normal ammonium acetate solution as described by [15] 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 [20]. The mineralogical study on the clay fraction of the soils was carried out based on random powder analysis using A PANalytical X'Pert Pro instrument (XRD) [21].

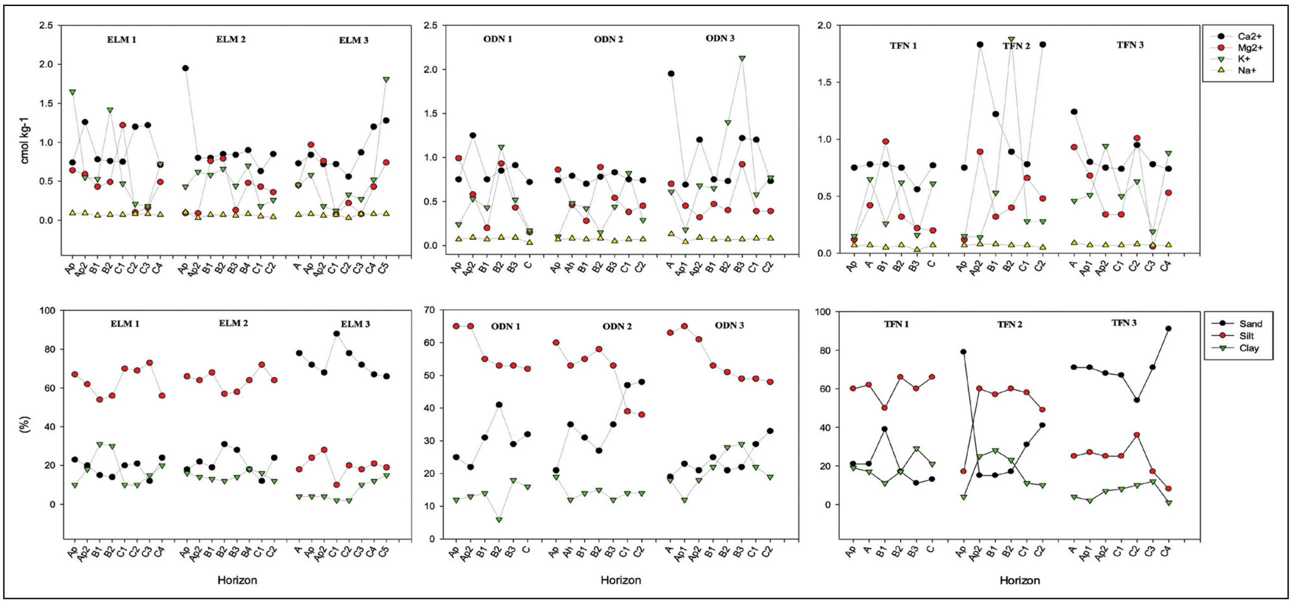

Figure 3. Scattered plot showing the distribution of Exchangeable bases and particle distribution of Elemebiri, Odoni and Trofani soils.

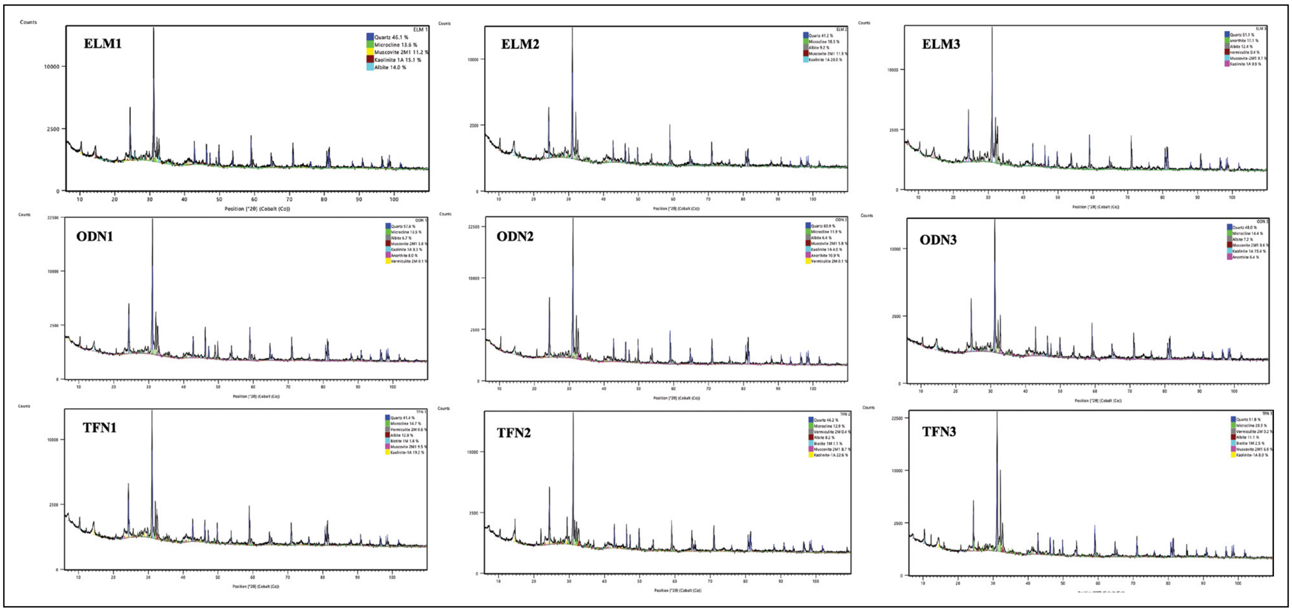

Figure 4. X-ray diffractogram of Elemebiri, Trofani and Odoni soils.

RESULTS AND DISCUSSIONS

Morphological Properties

Morphological characteristics of the Elemebiri, Odoni and Trofani soils are presented on Tables 1, 2, and 3, respectively. The soils were generally deep, no much variation in soil colour as most of the SMUs have Hues of 10 YR except some SMUs in Odoni dominated by hues of 7.5 YR. At the 18–31cm depth of the ELM3, few, medium, distinct 2.5 YR 3/3 mottles were observed and at the 38–69 cm depth of TFN3, many, medium, distinct, 10 YR 3/3 mottles were observed. The zone of water saturation during the flood season was at the soil surface for ELM3, ODN3 and TFN3, about 40 cm from the mineral soil surface for ELM2, ODN2 and TFN2, and at about 118 cm for ELM1, 117cm for ODN1 and 140cm for TFN1 (Tables 1, 2, and 3). All the studied profiles were considered hydromorphic because of the presence of mottles except ELM3 and TFN3. Since there was no perched water table below the 18–31cm depth of ELM3 and the 38–69 cm depth of TFN3, which were the observed mottled layers and no mottles occurred below them, the mottling in these layers was ascribed to

Table 1. Morphological characteristics of the Elemebiri soils and their classification

Horizon	Depth (cm)	Soil colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary
			Colour	Pattern			Moist	Wet		
ELM1 *(Aquic Dystrudepts/Fluvic Cambisol)*										
Ap	0–8	10YR3/2			fsil	Cr to WSAB	fr	Ss, Sp		cs
Ap2	8–21	10YR3/3			fsilcl	WSAB	sfi	Ss, Sp		cs
B1	21–34	10YR3/4			fsilcl	SAB	mfi	Ss, Sp		cs
B2	34–65	10YR3/4			fsil	SAB	mfi	Ss, Sp	C	cs
C1	65–90	10YR4/4			fsil	SAB	sfi	Ss, Sp		cs
C2	90–118	10YR4/4			fsilcl	SAB	sfi	Ss, Sp		cs
C3	118–150	10YR5/4	7.5YR5/6	F2D	fsil	SAB	sfi	Ss, Sp		cs
C4	150–200	10YR5/3	5YR4/6	C2D	fsil	SAB	sfi	Ss, Sp		
ELM2 *(Typic Epiaquepts/Fluvic Cambisol)*										
Ap	0–11	10YR2/2			fsil	Cr to WSAB	fr	ss, sp		cs
Ap2	11–19	10YR3/3			fsilcl	SAB	mfi	ss, sp		cs
B1	19–32	10YR3/2			fsilcl	SAB	mfi	ss, sp		cs
B2	32–42	10YR4/3			fsil	SAB	sfi	ss, sp		cs
B3	42–57	10YR5/3	7.5YR4/3		fsil	SAB	sfi	ss, sp		cs
B4	57–88	10YR5/2	7.5YR3/4	M2D	fsilcl	SAB	sfi	ss, sp		cs
C1	88–106	10YR5/2	7.5YR4/6	M2D	fsil	SAB	sfi	ss, sp		cs
C2	106–190	10YR5/1	7.5YR4/6	M2D	fsil	SAB	sfi	ss, sp		
ELM3 *(Eutric Udifluvents/Haplic-Fluvic Fluvisol)*										
A	0–18	10YR3/6			fsl	Cr	vfr	ns, np		cs
Ap1	18–31	10YR3/3	2.5YR3/3	F2D	fsl	Sg	fr	ns, np		c
Ap2	31–44	10YR6/4	–	–	ls	Sg	fr	ns, np		c
C1	44–68	10YR4/6	–	–	sl	Sg	fr	ns, np		cs
C2	68–81	10YR5/4	–	–	sl	Sg	fr	ns, np		cs
C3	81–123	10YR3/4	–	–	ls	VWSAB	sfr	ns, np		cs
C4	123–160	7.5YR4/4	–	–	ls	SAB	sfr	ns, np		g
C5	160–200	7.5YR2.5/3	–	–	ls	VWSAB	fr	ns, np		

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).; colour: YR=yellowish red; 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, vfr=very 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 2. Morphological characteristics of the Odoni soils and their classification

Horizon	Depth (cm)	Soil colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary
			Colour	Pattern			Moist	Wet		
ODN1 *(Humic Dystrudepts/Fluvic Cambisol)*										
Ap	0–23	7.5YR3/2			fsil	VWSAB	sfi	ss, sp	–	cs
Ap2	23–30	7.5YR4/4			fsil	WSAB	sfi	ss, sp	–	cs
B1	30–63	7.5YR4/4			fsil	SAB	mfi	ss, sp	–	dw
B2	63–117	7.5YR4/6			sil	SAB	mfi	ss, sp	–	dw
B3	117–160	7.5YR4/3	5YR4/4	M3D	sil	SAB	mfi	ss, sp	–	dw
C	160–200	7.5YR4/6	5YR4/6	M3P	sil	SAB	mfi	ss, sp	–	
ODN2 *(Typic Epiaquepts/Fluvic Cambisol)*										
Ap	0–20	10YR3/4			fsil	Cr	fr	ns, np	–	cs
A	20–40	10YR5/4			l	WSAB	sfi	ss, sp	–	cs
B1	40–110	10YR5/3	5YR6/4	F2D	sil	SAB	sfi	ss, sp	–	cs
B2	110–141	7.5YR5/4	5YR4/4	M3D	sil	SAB	Sfi	ss, sp	–	dw
B3	141–180	7.5YR5/2	5YR3/4	M3P	sil	SAB	sfi	ss, sp	–	cs
C	180–200	10YR5/1	5YR3/4	M3P	sil	SAB	sfi	ss, sp	–	
ODN3 *(Fluvaquentic Epiaquepts/Fluvic Cambisol)*										
A	0–5	7.5YR3/2			fsil	WSAB	sfi	ss, sp	–	dg
Ap1	5–11	7.5YR4/4	5YR5/3	C2D	sil	WSAB	Sfi	ss, sp	–	dw
Ap2	11–25	7.5YR4/4	5YR6/4	C2D	sil	SAB	sfi	ms, mp	–	dg
B1	25–41	7.5YR6/2	5YR6/1	C2D	sil	SAB	mfi	ms, mp	Fe-Mn	cs
B2	41–48	7.5YR4/4	5YR5/2	C2D	sicl	SAB	mfi	ms, mp	Fe-Mn	cs
B3	48–56	7.5YR5/4	5YR4/4	M3P	cl	SAB	mfi	ms, mp	–	cs
C1	56–122	7.5YR5/6	5YR4/4	M3P	l	SAB	mfi	ms, mp	–	cs
C2	122–200	7.5YR4/6	5YR4/6	M3P	l	SAB	mfi	ms, mp	–	

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).; colour: YR=yellowish red; 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, vfr=very 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 3. Morphological characteristics of Trofani Soils and their classification

Horizon	Depth (cm)	Soil colour	Mottles		Texture	Structure	Consistence		Concr.	Boundary
			Colour	Pattern			Moist	Wet		
TFN1 *(Aquic Dystrudepts/Fluvic Cambisol)*										
Ap	0–14	10YR3/4			fsil	SAB	sfi	ss, sp		cs
A	14–31	10YR3/4			fsil	SAB	sfi	ss, sp		cs
B1	31–55	10YR3/4			fsil	SAB	mfi	ss, sp		cs
B2	55–140	10YR3/6			fsil	SAB	mfi	ss, sp		cs
B3	140–150	10YR4/2	2.5YR3/4	C2D	fsilcl	SAB	mfi	ms, mp	C	cs
C	150–200+	10YR4/4	5YR4/6	M3P	fsil	SAB	mfi	ms, mp		
TFN2 *(Typic Epiaquepts/Fluvic Cambisol)*										
Ap	0–11	7.5YR3/3			fls	Cr	fr	ns, np		cs
Ap2	11–35	10YR4/4			fsil	SAB	sfi	ss, sp	C	cs
B1	35–44	10YR5/2			fsilcl	SAB	mfi	ss, sp		cs
B2	44–70	10YR5/3	5YR5/6	C2D	fsil	SAB	sfi	ss, sp		cs
C1	70–126	10YR5/2	5YR3/3	M3P	fsil	SAB	sfi	ss, sp		dg
C2	126–200+	10YR6/2	5YR3/3	M3P	l	SAB	sfi	ss, sp		
TFN3 *(Aquic Udifluvents/Haplic Fluvisol)*										
A	0–13	10YR3/3			fsl	M	sfi	ss, sp		dw
Ap1	13–23	10YR3/4			sl	Gr	fr	ns, np		dw
Ap2	23–38	10YR5/4			sl	Gr	fr	ns, np		cs
C1	38–52	10YR3/3	10YR3/3	M2D	sl	Gr	fr	ns, np		cs
C2	52–69	10YR4/6	10YR3/3	M2D	sl	Gr	fr	ns, np		cs
C3	69–83	10YR3/3			ls	Sg	l	ns, np		cs
C4	83–200+	10YR6/3			s	Sg	l	ns, np		

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); colour: YR=yellowish red; fil=fine silt loam, fsilcl=fine silty clay loam, l=loam, fsl=fine sandy loam, sl=sandy loam, ls=loamy sand; s=sand; Structure: cr=crumbly, SAB=sub angular blocky, gr=granular, sg=single grain; Consistence=friable, vfr=very friable, l=loose, sfi=slightly firm, mfi=moderately firm; ns=non sticky, np=non plastic, ss=slightly sticky, sp=slightly plastic, ms=moderately plastic, mp=moderately plastic; Concretions: c=carbon; Boundary: cs=clear smooth, dw=diffuse wavy, dg-diffuse gradual.

Table 4. Percentage distribution of clay mineral types in the soil mapping units

SMU	Percentage mineral in the soil									
	Quartz	Kaolinite	Vermiculite	Biotite	Muscovite	Microline	Albite	Anorthite	Chlorite	Zeolite
ELM1	46.1	15.1	nd	nd	11.2	13.6	14	nd	nd	nd
ELM2	41.2	20	nd	nd	11.3	18.3	9.2	nd	nd	nd
ELM3	51.1	9.9	0.4	nd	9.1	nd	12.4	17.1	nd	nd
ODN1	57.6	8.3	0.1	nd	5.8	13.5	6.7	8	nd	nd
ODN2	60.9	4	0.1	nd	5.8	11.9	6.4	10.9	nd	nd
ODN3	48	15.4	nd	nd	8.6	14.4	7.2	6.4	nd	nd
TFN1	41.4	19.2	0.6	1.8	9.5	14.7	12.8	nd	nd	nd
TFN2	46.2	22.6	0.4	1.1	8.7	12.9	8.2	nd	nd	nd
TFN3	51.8	8	0.2	2.5	6	20.3	11.1	nd	nd	nd

nd: Not detectable.

the parent materials of the specific layers which indicated heterogeneity in parent materials of the specific SMUs. No saturation zone was found in any of the profiles during the dry season. All the profiles therefore were considered to be influenced by an annual cycle of wet/dry soil moisture regimes which qualified as 'udic' moisture regimes [13]. The drainage condition of the profiles was dictated by the rainy season and the annual Niger River floods. Subsurface greyization (gleys) was a notable morphometric feature in the levee slope soils (ELM2, ODN2 and TFN2) and ODN3 of the flood plain. Regular decrease of organic carbon down the profiles with hydromorphism within the surface 50 cm was observed for ELM2, ODN2 and TFN2 and within 5 cm for ODN3. The presence of mottles in these soils indicated fluctuation of ground water table while the presence of gleys in the lower horizons of ELM2, ODN2 and TFN2 indicated perennial hydromorphism as noted previously by [5]. Greyish colouration at lower depths is associated with ground water influence or poor drainage [3] and/or such soil layer is subject to groundwater influence in most part of the year [4]. The pedons showed mostly clear and smooth horizon boundaries with some diffuse, wavy, and gradual boundaries, reflecting the recentness of the soils and young soil development or rejuvenation processes [5] and different seasons of deposition of the parent materials. Moreover, no clay movement from A to B horizon was noticed confirming young soil development or rejuvenation processes. Similarly, cutans (clay skins) were absent on ped surfaces as there was no illuvial accumulation of clays in the pedons. The presence of many mica flakes in the profiles corroborated the incipient nature of the soils. Surface and subsurface texture of the SMUs was fairly uniform, dominated by silt loam and silty clay loam except ELM3 and TFN3 dominated by sandy loam and loamy sand. The ELM3 and TFN3 SMUs, of recent alluvial soils in the channels of present active rivers received annual alluvial materials enrichment from the yearly floods and were structurally weak. Structural development in the other SMUs was moderately strong.

Physico-Chemical Properties

The texture of the soils was dominantly silt loam followed by silty clay loam and loam except ELM3 and TFN3, dominated by loamy sand and sandy loam (Figure 3). The dominance of sand in ELM3 and TFN3 (Figure 3) indicated that the SMUs have high infiltration rate and low water holding capacity with possibility of moisture stress during dry months [22, 23]. The clay distribution within ELM1, ELM2, ODN1, ODN2, ODN3, TFN1 and TFN2 SMUs was irregular. Reported [24] 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. Higher silt/clay ratio in the surface layers reflected annual alluvial enrichment of the surface through deposition by the annual floods. Report [25] indicated that soils with silt/clay ratios below 0.15 indicated that such soils are of old parent material, while those above 0.15 are of young parent materials with low degree of weathering. Recorded [24] 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.

The SMUs were moderately acidic to neutral, pH (water) ranging from 5.31 to 7.00 for Elemebiri soils, 5.33–6.70 for Odoni soils and 5.30–6.80 for Trofani soils, respectively (Figure 2). 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 (Figure 2) with increase in depth [26]. Reported [27] pH of 6.0 to 7.0 as the optimum pH for most agricultural crops while [28] and [29] 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 as reported by [28]. This is an indication that the SMUs need some form of soil amendments. Attributed [5] increase in soil pH with depth to ferrolysis which is acidification of topsoil caused by continual displacement of bases by ferrous ion during the reduction phase associated with 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 [30]. Positive ΔpH values were obtained for all the soils indicating that the soils were all negatively charged.

Organic matter content of 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 (Figure 2). Generally, organic carbon and indeed organic matter levels decreased irregularly with soil depth which agreed with the reports of previous authors in Nigeria [31, 32] and [30] in Ethiopia. Also reported [5] organic C decrease with soil depth for Bangladeshi soils and low organic C content was attributed to rapid decomposition of organic matter under hyperthermic temperature regime. For 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 is necessary to note that organic matter mineralization rate in the soils is high due to high temperatures and heavy rainfall as 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 intermittent flooding and drying which is known to favour N loss through nitrification-denitrification processes [29]. Reported [33] 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 are likely to have reasonable mineralization potential while the mineralization potential of ELM3, ODN1 and TFN2 was low.

Available P distribution apparently decreased with depth in ELM and ODN with an inconsistent distribution pattern in TFN soils. Available P concentration in ELM and ODN agreed with the results of [34] in a study of soils along a toposequence in Ethiopia that reported available P showing an increasing trend down topographic position and a decreasing trend with depth which they attributed to increase in clay content and decrease in soil organic matter content. Whilst the inconsistency in distribution of available P in TFN with an expected distribution pattern of organic matter in the same SMU, the result, however, could be attributed to the differences in source of parent material. Similar variations were observed in ELM soils where organic matter was seen to be inconsistent with available P distribution. Moreover, the distribution of P within the profiles showed no regular pattern of decrease which agreed with the findings of [35]. 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 aluminum oxides in the soils. Low P availability in tropical soils can as well be 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.

Exchangeable K varied from 0.18–1.81 cmol kg^{-1} in Elemebiri, 0.10–2.13 cmol kg^{-1} in Odoni and 0.14–1.88 cmol kg^{-1} in the Trofani soils (Figure 3). Also, the ECEC values were low, ranging from 1.49–6.11 cmol kg^{-1} in Elemebiri soils, 2.47–8.06 cmol kg^{-1} in Odoni soils, and 2.79–6.37 cmol kg^{-1} in Trofani Exchangeable Ca^{2+} dominated the exchange complex of the SMUs followed by Mg^{2+}. 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. Reported [5] Ca^{2+}/Mg^{2+} ratios of less than unity in Bangladeshi soils, attributing this development to loss of Ca^{2+} due to gleization. Reported [26] 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 to a lesser extent, possible loss of Ca by gleization as noted previously by [5]. 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 [36]. 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. Based on the categorisation of [28], it is obvious that K in most layers of the pedons was medium to very high.

The exchange acidity of 45% of the soils was 2.0 cmol kg^{-1} and above suggesting that 45% of the soils were slightly to strongly acidic [8], Odoni soils having higher total exchange acidity.

MINERALOGICAL COMPOSITION

Table 4 shows the variation in the composition of clay mineral assemblage in the pedons. Ten different mineral phases were identified in the nine locations, kaolinite, quartz, muscovite ($KAl_2(AlSi_3O_{10})(OH,F)_2$) and albite ($NaAlSi_3O_8$) identified in all the locations. Quartz was the dominant mineral in the locations while kaolinite was easily detectable and dominated the clay fraction. Microline was detected in all the locations except ELM3. The occurrence of vermiculite and biotite was low, vermiculite, detected only in ELM1, ELM2 and ODN3 and biotite, in Trofani soils (TFN1, TFN2 and TFN3) only. The X-ray diffractograms of the pedons are presented in Figure 4. The dominance of silt-sized quartz fraction in the clay mineral assemblage further confirmed the assertion that the soils were recent in origin. Kaolinite, muscovite, microline ($KAlSi_3O_8$) and albite of the plagioclase group were also prominent (Table 4). Anorthite [Ca $(Al_2Si_2)O_8$], another mineral of the plagioclase group was present in ELM3 out of the nine locations. There was also vermiculite, an interstratified clay mineral, present in six (ELM3, ODN1, ODN2, TFN1, TFN2, and TFN3) SMUs though not in large quantities and biotite [$K(Mg.Fe)_2(AlSi_2O_{10})(OH,F)_2$] in TFN1, TFN2, and TFN3. These findings corroborate an earlier report by [37]. It was further reported that kaolinite, quartz, mica, vermiculite and interstratified or mixed layer silicates were present in the clay fractions of Mbiama-Kaiama soils of the same meander belts region of Bayelsa State. Similarly [38], identified quartz, kaolinite, illite, smectite, vermiculite and interstratified types as common minerals in the silt-clay fraction of floodplain soils in Kogi State. In the [39] characterization of clays in Odukpani, South-eastern Nigeria reported that Kaolinite is the dominant clay mineral.

Another major observation in the clay mineralogy of the soils was the near absence of ferromagnesian minerals in the soils. The only minerals of the ferromagnesian family were vermiculite and biotite (Table 4) whose quantities were low. This may account for the low levels of basic cations such as Mg and Ca in the soils. Consequently, Mg:K ratio in the soils was low which placed most of the pedons in the marginally suitable class for oil palm production. However, the presence of several K bearing minerals in the pedons such as the micas (biotite and muscovite) and the feldspars suggest that the K pool in the pedons could naturally be replenished. This agreed with the medium to high K concentration results recorded in most of the pedons.

Among the silicate clay minerals, kaolinite was dominant (Table 4) which agreed with findings of [39]. Kaolinization, therefore, is the dominant clay forming process in these pedons hence the dominance of kaolinite among silicate clays in all the pedons. Vermiculite and biotite, the only ferromagnesian minerals detected were low and were not detected in most of the pedons which could be evidence that parent materials are heterogenous. The near absence of ferromagnesian minerals in the clay mineralogical composition of the soils and the dominance of kaolinite implied that the soils are dominated by low activity clays (LAC) and can easily be eroded. Consequently, split application of recommended fertilizers rates is suggested to avert leaching loss of nutrients when applying fertilizer. In addition, cultural practices such as bush burning that destroy soil organic matter should be avoided to maintain organic matter levels in the soils.

Soil Properties and Nature of the Parent Materials

Texture (Figure 3), organic carbon distribution (Figure 2) and clay mineralogy (Table 4 and Figure 4) are features commonly used as indicators of the homogeneity or otherwise of the parent materials. The very fine sand and fine sand proportions are used to indicate lithologic discontinuities within individual soil profiles because these two size fractions form the greatest percentage of the sand fraction, and are assumed to be made up of quartz and other resistant primary minerals. Though sand was not separated into fine, medium and coarse in this study, the distribution pattern of sand in some of the SMUs presented a lot about the parent materials. Figure 3 indicated significant change and differences in the distribution pattern of sand in the different horizons of ELM3, ODN1, ODN2, TFN2, TFN3, and to a lesser extent, ODN3 and TFN1. Similar observation was made in the distributional pattern of silt and in particular clay in the soils. The textural diversity observed between the different SMUs was ascribed to differences in the sources of the water-borne sediments and flow rate of the flood water at the time of deposition of the parent materials. Whereas the parent materials of ELM3 and TFN3 were deposited during the period of high flood as they are recent alluvial soils from the channels of present active Niger and Forcados Rivers and dominantly constituted by sand-sized particles (sandy loam, loamy sand and sand), other profiles were dominated by silt loam, silty clay loam and loam. The finer soil particles, in suspension, probably were transported for longer period of time over greater distances and deposited at low flood period when there was less turbulence than the case of ELM3 and TFN3, deposited during the high flood water under high current. Reported [24] higher amount of silt in JG3 profile of Southern Guinea Savannah of Nigeria and linked it to the seasonal depositional effect of the seasonal stream and the Suleja water reservoir inundating the JG3 area. The 0–11 cm layer of ELM2 seems to be of different parent material from the rest of the horizons as the proportion of sand in this layer was 79% as compared to other horizons with 40% or less sand. The high concentration of sand in this layer cannot be ascribed to clay eluviation or surface erosion. The dominance of sand in the two bottom layers of ODN2 also showed that these layers were of different parent material (Figure 3).

Organic carbon distribution pattern in the soils (Figure 2) indicated stratification. Irregular decrease in organic matter content with depth was consistent with the properties of fluvents [13]. The organic C distribution pattern in ELM1, ELM2, ELM3, ODN2, ODN3, TFN1, TFN2 and TFN3 did not suggest uniform parent materials with the observed abrupt increase in organic C in some horizons down the profile of some SMUs. As shown on Figure 2, organic C abruptly increased from 0.7% in the 90–118 cm layer to 1.07% in the 150–200 cm layer of ELM1, 0.11% in the 42–57 cm layer to 0.16% in the 88–106 cm layer of ELM2, 0.2% in the 21–37 cm layer to 0.73% in the 79–149 cm layer of ODN2, 0.31% in the 25–41 cm layer to 0.99% in the 41–48 cm layer and 0.31% in the 48–56 cm layer to 0.86% in the 122–200 cm layer of ODN3, 0.21% in the 55–140 cm layer to 1.04% in the 150–200 cm layer of TFN2 and 0.30% in the 38–52 cm layer to 0.68% in the 52–69 cm layer of TFN3 which probably indicated heterogeneity.

CONCLUSIONS

The floodplain soils of the Lower Niger River and the two major tributaries (Nun and Forcados) showed some degree of differences in morphological, physical, chemical and mineralogical characteristics, as well as heterogeneity of parent materials. 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. The SMUs were dominated by quartz and low activity clays, kaolinization, being the dominant clay mineral forming process. The study, however, found out that flooding, wetness and soil fertility are major constraints to agricultural intensification that must be addressed should government desire achievable results for sustainable crop production. The findings therefore, provides a robust and reliable guide for the Bayelsa State government to draw effective agricultural policies not only for sustainable crop production ventures within these affected areas but for the state at large as soils of the entire state are likely to have similar parent materials. Further morphological and mineralogical studies are therefore recommended on a larger scale so as to provide both State and the Federal governments the needed information for proper agricultural intensification programmes.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] A. U. Akpan-Idiok and P. O. Ogbaji, "Characterization and classification of Onwu River floodplain soils in Cross River State, Nigeria," International Journal of Agricultural Research, Vol. 8, pp. 107–122, 2013. [CrossRef]

[2] G. S. Effiong and T. O. Ibia, "Characteristics and constraints of some river flood plains soils to crop production in Southeastern Nigeria," Agricultural Journal, Vol. 4, pp. 103–108, 2009.

[3] I. Esu, "Soil characterization, classification and survey," HEBN Publishers Plc, Lagos, 2010.

[4] M. M. Hossain, Z. H. Kpan, M. S. Hussain and A. R. Mazumder, "Characterisation and classification of some intensively cultivated soils from the Ganges river floodplain of Bangladesh," Dhaka University Journal of Biological Sciences, Vol. 20, pp. 71–80, 2011. [CrossRef]

[5] Z. H. Khan, M. S. Hussain and F. Ottner, "Morphogenesis of three surface water gley soils from the megna floodplain of Bangledesh," Dhaka University Journal of Biological Sciences, Vol. 21, pp. 17–27, 2012. [CrossRef]

[6] A. Ojanuga, "Clay mineralogy of soils in the nigerian tropical savanna regions," Soil Science Society of America Journal, Vol. 43, pp. 1237–1242, 1979. [CrossRef]

[7] A. A. Dickson, J. O. Kamalu, O. J. Tate and P. T. Ogboin, "Characterization and classification of some Alluvial soils of the Lower Niger River floodplains in Bayelsa State, Nigeria," Bulgarian Journal of Soil Science Agrochemisty and Ecology, Vol. 55, pp. 45-62, 2021.

[8] C. I. Ernest and E. U. J. Onweremadu, "Classification of soils along Ogochie River Floodplain in Niger-Okpala, Imo State,Southern Nigeria," Journal of Global Research, Vol. 2, pp. 78–83, 2016.

[9] R. Lal, "Managing world soils for food security and environmental quality," Advances in Agronomy, Vol. 74, pp. 155–192, 2001.[CrossRef]

[10] F. R. Kutu, J.A.N. Asiwe, "Assessment of maize and dry bean productivity under different intercrops and fetilizer regimes," African Journal of Agricultural Research, Vol. 5, no. 13, pp. 1627–1631, 2010.

[11] F. R. Kutu and M. L. Diko, "Mineralogical considerations in soil fertility management on selected farmlands in Limpopo and northwest provinces, South Africa," in In An innovative perspective on the role of clays and clay minerals and Geophagia Book of conference proceeding of the first international conference of clays and clay minerals in Africa and second international conference on Geophagia in Southern Africa, South Africa, 2011.

[12] C. A. Shisanya, M. W. Mucheru, D. N. Mugendi and J. B. Kung'u, "Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya," Soil and Tillage Research, Vol. 103, no. 2, pp. 239–246, 2009. [CrossRef]

[13] D.W. Smith, "Soil survey staff, keys to soil taxonomy," 11th ed., United State Department of Agriculture, Natural Resource Conservation Service, Washington D.C., pp. 372, 2010.

[14] P. Day, "Particle fractionation and particle size analysis," Methods of soil analysis," American Society of Agronomy, Madison, 1965.

[15] G. Estefan, R. Sommer and J. Ryan, "Methods of soil, plant and water analysis: A manual for the West Asia and North Africa," International Center for Agricultural Research in thee Dry Areas (ICARDA), Beirut, 2013.

[16] V. J. G. Houba, J. J. Van Der Lee and I. Novozamsky, "Soil and plant analysis, part 5B soil analysis procedures, other procedures, Wagnengin University, Wageningen, 1995.

[17] R. Bray and L. Kurtz, "Determination of total, organic and available forms of phosphorus in soils," Soil Science, Vol. 59, no. 1, pp. 39–45, 1945. [CrossRef]

[18] J. Anderson and J. Ingram, "Tropical Soil biology and fertility: A handbook of methods," CAB International, Oxford, pp. 12–21, 1993.

[19] M. E. Sumner and B. A. Stewart, "Soil crusting: chemical and physical processes, 1st ed.: Lewis Publishers, Athens, Georgia, p. 372, 1992.

[20] E. Kamprath, Soil acidity and liming, In P.A. Sanchez (Ed.). "A Review of Soil Research in Tropical Latin America," North Carolina Experimental Station, North Carolina, 1970.

[21] M. Loubser and S. Verryn, "Combining XRF and XRD analyses and sample preparation to solve mineralogical problems," South African Journal of Geology, Vol. 111, no. 2-3, pp. 229–238, 2008. [CrossRef]

[22] B. Senjobi, "Comparative assessment of the effect of land use and land use type on soil degradation and productivity in Ogun State," Ibadan, 2007.

[23] B. A. Senjobi, R. T. Idehen, O. O. Oduntan and J. K. Adesodun, "Characterization and morphogenetic variability of soils under organic-based oil palm plantations in Southwestern Nigeria," Journal of Organic Agriculture and Environment, Vol. 4, no. 1, pp. 17–27, 2016.

[24] B. A. Lawal, A. G. Ojanuga, P. A. Tsado and A. Mohammed, "Characterization, classification and agricultural potentials of soils of toposequence in southern Guinea Savanna of Nigeria," World Academy of Science, Engineering and Technology International Journal of Agricultural and Biosystems Engineering, Vol. 7, no. 5, pp. 148–152, 2013.

[25] C.N. Egbuchua and S. Ojobor, "Characterization of some hydric soils in the Niger Delta region of Nigeria for land evaluation purposes," International journal of Advanced Biological Research, Vol. 1, no. 1, pp. 77–82, 2011.

[26] S. W. Buol, R. J. Southard, R. C. Graham and P. A. McDaniel, "Soil genesis and classification, 6 ed., John Wiley & Sons, New York, pp. 560, 2011. [CrossRef]

[27] J. W. C. Wong, K. M. Lai, D. S. Su and M. Fang, "Avilability of heavy metals for Brassica Chinensis grown in an acidic loam soil amended with domestic and sewage sludge," Water, Air and Soil Pollution, Vol. 128, pp. 339–353, 2001. [CrossRef]

[28] R. Jahn, H. P. Blume, V. B. Asio, O. Spaargaren and P. Schad, "Guidelines for soil description," Food and Agricultural Organization of the United Nation," FAO, Rome, 2006.

[29] N. Brady and R. Weil, "The nature and properties of soils," 14 ed., Pearson Princeton Hills, New Jersey, 2008.

[30] Y. Alemayehu, H. Gebrekidan and S. Beyene, "Pedological characteristics and classification of soils along landscapes at Abobo, southwestern lowlands of Ethiopia," Journal of Soil Science and Environmental Management, Vol. 5, no. 6, pp. 72–82, 2014.

[31] S. Idoga and D. E. Azagaku, "Characterization and classification of Janta Area, Plateau State of Nigeria," Nigerian Journal of Soil Science, Vol. 15, pp. 116–122, 2005.

[32] S. O. Atofarati, B. S. Ewulo and O. Ojeniyi, "Characterization and classification of SWoils on two toposequence at Ile-Oluji, Ondo State, Nigeria," International Journal of Agricultural Science, Vol. 2, pp. 642–655, 2012.

[33] T. K. Hartz, "Soil testing for nutrient availability: Procedures and interpretation for california vegetable crop production," University of California, Davis, 2007.

[34] A. Abate, K. Kibret, H. Gebrekidan and A. Esayas, "Determination of physico-chemical properties and agricultural potentials of soils in Tembaro District, KembataTembaro Zone, Southern Ethiopia," Eurasian Journal of Soil Science, Vol. 8, no. 2, pp. 118–130, 2019. [CrossRef]

[35] B. O. Nuga, N. C. Eluwa, G. E. Akinbola and C. C. Nwokocha, "Characterization and Classification of soils along a toposequence in Ikwano Local Government Area of Abia State, Nigeria," Agriculture Journal, Vol. 1, pp. 192–197, 2006.

[36] S. L. Tisdale, W. L. Nelson, J. D. Beaton and J. L. Havlin, "Soil fertility and fertilizers", 5th ed., Prentice Hall, New Delhi, 2004.

[37] P. Loganathan, A.A. Dickson, and N.O.Isirimah, "Potassium supplying capacity of soils formed on different geological deposits in the Niger Delta region of Nigeria," Geoderma, Vol. 65, pp. 109–120, 1995. [CrossRef]

[38] M. Ukubiala, "Characterization and classification of river benue floodplain soils in bassa local government area of Kogi State," Kogi State University, Kogi, 2012.

[39] V. N. Osobor, P. C. Okafor, K. A. Ibe and A. A. Ayi, "Characterization of clay minerals in Odukpani, Southeastern Nigeria," African Journal of Pure and Applied Chemistry, Vol. 13, pp. 79–85, 2009.