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CHARACTERIZATION, CLASSIFICATION AND SUITABILITY EVALUATION OF SOILS FORMED IN FLUVIAL DEPOSITS WITHIN EASTERN PART OF KOGI STATE IN NIGERIA FOR RICE AND MAIZE PRODUCTION

[*1,2]Ukabiala M.E., [2]Ezeaku P.I., [3]Kolo J., [2]Umeugokwe C.P. and [4]Okenmuo F.C.

[1]Department of Soil Science, University of Agriculture & Environmental Sciences, Umuagwo, Imo State, Nigeria
[2]Department of Soil Science, University of Nigeria, Nsukka, Nigeria
[3]National Drug Law Enforcement Agency, Ikoyi-Lagos, Nigeria
[4]Department of Soil Science, Chukwuemeka Odumegwu Ojukwu University, Igbariam, Nigeria

*Corresponding author's email: successfulmadu@yahoo.com

ABSTRACT
The impact of rice and maize production on food security in Nigeria cannot be over-emphasized. The aim of this research was to characterize, classify and evaluate the suitability of soils formed in fluvial deposits within eastern part of Kogi State in Nigeria for rice and maize production. This was supported by the fact that the knowledge of the characteristics and soil groups of fluvial deposits in soils is an integral part in soil suitability evaluation as well as management. Four (4) soil profile pits were sunk within the research area. The pedons were located within the 19a mapping unit of the soil map of Nigeria which has the fluvial deposits. Pedons were adequately described as soil samples were collected from pedogenic horizons, and preserved in well-labelled polyethylene bags, transported to the Laboratory for analyses. The findings revealed that the soils were characterized by dominant gray (10YR4/1) and dark reddish gray (10R4/1) in the surface soils and dominance of various shades of gray in the subsurface soils. Most of the soil structures were single-grained and subangular blocky at the surface and subsurface soils respectively. The soil texture was sandy clay loam and sandy loam in the A horizons. The soil reaction showed mean values of 6.1 and 5.5 at the surface and subsurface horizons with base saturation highest (91%) at C1 horizon of 19a$_3$ pedon. The pedons were classified as inceptisols, and were currently not suitable (N$_1$) for rice cultivation but marginally suitable (S$_3$) for maize cultivation.

Key words: fluvial, suitability, mottles, inceptisols, classification, characterization

INTRODUCTION
Fluvial deposits are remains that are transported and deposited by rivers in a continental environment (Slatt, 2013). The soils of fluvial deposits are associated with streams and rivers. The global rise in sea levels in recent years and an upsurge in incidence of flooding as a result of climate change and global warming, have led to more fluvial deposition in river floodplains (Morita, 2011). The changes in the physical properties include soil structure, texture, colour, aeration and temperature, while changes in the chemical properties may involve organic matter accumulation, and leaching of nitrogen and potassium from the soil (Iheka *et al*., 2015; Eleke *et al*., 2018; Okenmuo *et al*., 2020). The production of rice and maize as staple crops is largely influenced by soil characteristics (Ukabiala, 2019). The knowledge of soil characteristics is an integral part in land suitability evaluation as well as management. There is therefore need to provide information on the physical and chemical properties of soils developed in fluvial deposits in eastern part of Kogi State to enhance productivity. This research was aimed at the characterization and classification of soils formed in fluvial deposits within eastern Kogi State in Nigeria as well as suitability evaluation for the production of rice and maize.

MATERIALS AND METHODS
Research Area
The research area is situated Obakwume, Ajekwu, Itobe and Ugwolawo within the eastern zone of Kogi State, which is situated within the middle belt of Nigeria. Kogi State lies within latitudes 6°51'0"N to 7°54'0"N and longitudes 6°45'0"E to 7°38'0"E (Figure 1) with altitudes ranging from 38 to 426 m asl. Kogi East covers an area of ca. 13,653 km^2 (Ukabiala, 2019), and is bounded on the West by the Niger River, North by the River Benue, East by Benue State and South by Anambra State (Figure 1).

Climate of the Research Area
Two distinct seasons, rainy and dry seasons, define the study area. The rainy season usually lasts from Apr. to Oct, and the dry season from Nov. to Mar. (Weatherbase, 2011). A part of the dry season is very

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dusty and cold as a result of the northeasterly winds which bring about the harmattan. This zone has an annual rainfall ranging from 1100 to 1300 mm. The average monthly temperature varies between 17 and 36ºC (Amhakhian and Osemwota, 2012). The highest temperature (36°C) is recorded during the dry season. The mean relative humidity is lowest during the dry season and highest during the rainy season of the years, giving 15 and 67%, respectively (Gideon and Fatoye, 2012).

Vegetation and Land Use in the Research Area

The research area cuts across the rain forest belt and the southern guinea savannah. The rain forest vegetation includes rich deciduous and occasional stunted trees such as Iroko (*Chlorophora* spp.) and Mahogany (*Khaya* spp.). The Guinea Savannah belt has tall grasses and some trees. These are green in the rainy season with fresh leaves, but the land is open during the dry season, showing charred trees and remains of burnt grasses. The trees which grow in clusters are up to 6 m tall, interspersed with grasses which grow up to about three metres. These trees include Locust bean (*Ceratonia siligua*), Shea butter tree (*Vitellaria paradoxa)*, Oil bean (*Phaseolus* spp.) and the Isoberlinia trees. Other plant species common to this area are Dulse (*Carissa edulis*), African Rosewood (*Pterocarpus erinaceous),* Amboina wood (*Pterocarpus indicus*), Persimmon (*Diospyros virginiana*), Venus's Flytrap (*Dionaea muscipula),* Banyan (*Ficus benghalensis*), Tumbleweed (*Amaranthus graecizans*), African whitewood called Obeche (*Triplochiton scleroxylon*), Sumac (*Rhus coriaria*), Balsam (*Impatiens pallida*)*,* and Box leaf myrtle (*Paxistima myrtifolia*)*.* At the floodplains are also found Palms (*Guineensis* spp.)*,* Holly *(Ilex opaca*), Plane tree (*Platanus orientalis*), Willow (*Salix babylomica*) and ferns (*Filicinophyta* spp.) (White, 1983).

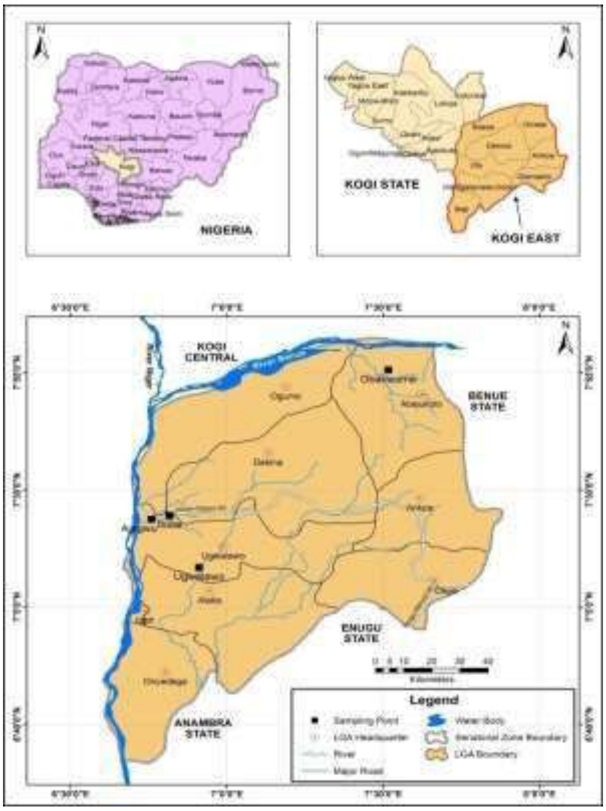

Figure 1: Map of Kogi East showing the sample points

Geology of Kogi East

The geology comprises of basement complex rocks (magmatite, gneiss and older granite) extending towards the lower Niger valley (Figure 2). The various sedimentary rocks of River Niger and Benue extend south-eastwards through Enugu and Anambra States. Amhakhian and Osemwota (2012) reported geologic formation of cretaceous sediments in a landform within the study area. A study of sediment geochemistry of River Okura found within this zone has confirmed that the study area falls within the Anambra Sedimentary Basin which is cretaceous in age (Gideon and Fatoye, 2012). The study further revealed that the rocks have low silica (SiO_2) but high iron (Fe) content which strongly suggests *lithic arenite* type of sandstone. Parts of the study area have also been found to be made up of geologic materials such as Awgu shale group in the floodplain and false-bedded keana sandstones (Fagbami and Akamigbo, 1986).

Field Work

Four (4) soil profile pits were sunk within the research area. The selection of the pedons was guided by a re-drawn soil map of Kogi East (Figure 3) from Soil Map of Nigeria (FDALR, 1990) which served as a base map. The pedons were located within the 19a mapping unit of the soil map, which has the fluvial deposits. They were sited at Itobe ($19a_1$), Ugwolawo ($19a_2$), Ajegwu ($19a_3$) and Obakwume ($19a_4$). The dimensions of the profile pits were 200 × 150 × 200 cm for length, breadth and depth respectively, depending on the depth to impenetrable layers (Plate 1). The site specific international coordinates of the pedons were georeferenced using a hand-held Etrex high sensitivity Global Positioning System (GPS). The profile pits and their environs were described (field characterization) following USDA guidelines for description and sampling soils (Schoeneberger *et al*., 2012). Abney level equipment was used to determine the slope angles on the sites of the profile pits. Core samples were collected with core samplers of 99.6 cm^3 by volume from the pits at the surface and subsurface of pedogenic horizons. The core samples were used for the examination of some soil physical characteristics. Soil samples were collected from the pedogenic horizons starting from the base of the profiles to avoid contamination.

The soil samples collected were preserved in well-labelled polyethylene bags and transported to the University of Nigeria Nsukka Soil Science Laboratory for physicochemical analyses.

Figure 2: Geological map of Kogi East
Source: Department of Geography, Kogi State University, Anyigba

Figure 3: Soil map of Kogi East
Reproduced from Soil map of Nigeria (FDALR, 1990)

Physico-chemical Analyses of Soils from the Research Area

Particle size distribution was determined on the < 2 mm fraction of the air-dry and sieved samples using Bouyoucous' (1962) hydrometer method. Sodium hydroxide was used as dispersant. The soil textural classes were read out from the USDA soil textural triangle. Bulk density was determined by the core and excavation methods described by Landon (1981) by using the expression:

Soil bulk density =
oven dry weight of soil / volume of soil.

Soil porosity was calculated with the values of the bulk density using the method outlined by Vomicil (1965) and Brady and Weil (2002):

$$\text{Total porosity (\%)} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times \frac{100}{1}.$$

Soil saturated hydraulic conductivity (K_{sat}) was determined based on Klute and Dirksen (1986) method and calculated by using the transposed Darcy's equation for vertical flows of liquids:

$$K_{sat} = \frac{QL}{At.\Delta H};$$

where K_{sat} is saturated hydraulic conductivity (cm h^{-1}), Q is steady-state volume of water outflow from the entire soil column (cm^3), A is cross-sectional area (cm^2), t is time interval (h), L is length of the sample (cm), and ΔH is change in the hydraulic head (cm).

Soil pH was determined in water and 1N KCl solution using a soil solution ratio of 1:2.5 with the aid of a glass electrode pH meter (McLean, 1982). Organic carbon was determined by wet dichromate acid oxidation method (Nelson and Sommers, 1982). Total nitrogen was estimated by the macro-kjeldahl digestion method (Bremner and Mulvaney, 1982). Available phosphorus was obtained using Bray II bicarbonate extraction method (Olsen and Sommers, 1982), using 0.03N ammonium fluoride with 0.1N HCl. The phosphorus in the extract was determined with a photo-electric colorimeter. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OAc (pH 7.0) using 1:10 soil-water ratio. The K and Na in the extract were determined with Flame Photometer while Ca and Mg were determined by atomic absorption spectrophotometry (Thomas, 1982).

Exchangeable sodium percentage (ESP) was calculated by the formula of Soil Survey Staff (1999):

$$\text{ESP} = \frac{\text{Exchangeable Sodium}}{\text{Cation Exchange Capacity}} \times \frac{100}{1}.$$

The titration method, as outlined in selected methods for soil and plant analysis (Thomas, 1982), was used in the determination of the exchangeable acidity (EA). The samples were extracted with 1N KCl solution and the extract titrated with 0.05 NaOH to a permanent pink end point using phenolphthalein indicator. Total exchangeable bases (TEB) was obtained by the summation of the four basic cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) (Rhoades, 1982). Cation exchange capacity (CEC) of the soils was determined with 1N NH_4OAc, pH 7.0 (Rhoades, 1982). The effective CEC (ECEC) of the soil was estimated by the summation of the TEB and EA (Rhoades, 1982).

The percentage base saturation (PBS) was derived by dividing the TEB by the CEC obtained and multiplying by 100 (Rhoades, 1982).

Aluminium saturation percentage (ASP) was obtained as the ratio of aluminium concentration in the soil to the ECEC of the soil multiplied by 100 (Soil Survey Staff, 1999).

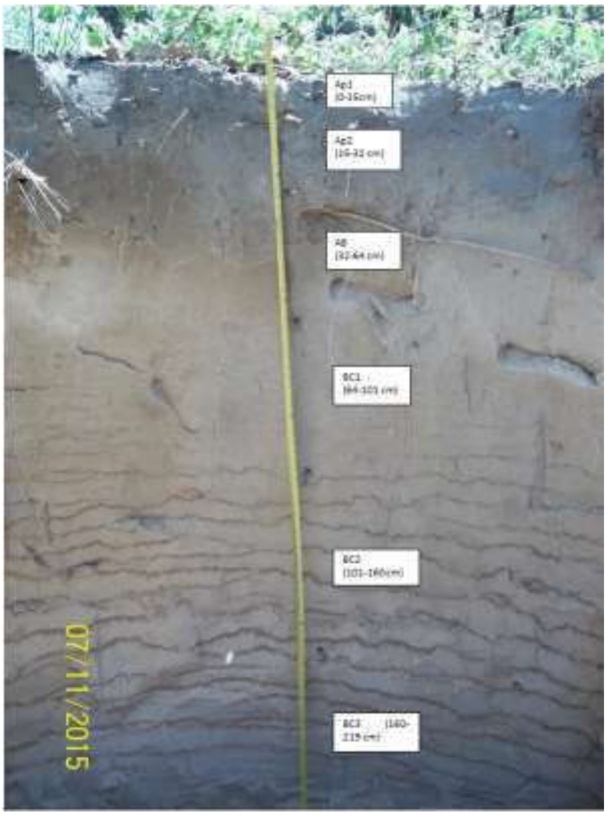

Plate 1: A typical soil profile of the 19a soil mapping unit at Itobe ($19a_1$) in Kogi East

Land Suitability Evaluation

The suitability of the soils for rice and maize was evaluated using the qualitative (conventional) and quantitative (parametric) methods (Udoh and Ogunkunle, 2012; Ezeaku and Tyav, 2013). The qualitative approach involves the matching of the crop requirements with the soil characteristics. The most limiting characteristic was identified which determined the class of suitability of each pedon for each of rice and maize. Under this approach, the soils were classified as being highly suitable (S_1), moderately suitable (S_2), marginally suitable (S_3), currently not suitable (N_1) or permanently not suitable (N_2), based on the limitations. The limitations were indicated by lower-case letters with mnemonic significance. The parametric (quantitative) approach to this evaluation was the numerical rating of some selected land qualities on a scale of 0 to 100 indicating very low to optimum values and according to the intended land utilization type (Table 1). The ratings were referenced to the established land requirements for each crop (Tables 2 and 3). The values of the ratings were used to calculate the Land Index (Current and Potential), following an additive model as stated in Ezeaku and Tyav (2013) as thus:

$$\text{Li} = \text{A} + \frac{\text{B}}{100} + \frac{\text{C}}{100} + \frac{\text{D}}{100} + \cdots + \frac{\text{F}}{100};$$

where Li is the Land Suitability Index, A is the overall lowest characteristics ratings and B, C ..... F are different ratings for each property. Here, the characteristic with the lowest value was added to the sum of the ratio of B, C ... F to 100.

Soil Classification

The soils were classified following the United States Department of Agriculture (USDA) classification system (Soil Survey Staff, 2014), and International Soil Classification System for naming Soils and Creating Legends for Soil Map (FAO-WRB, 2014).

Table 1: Class rates of soil suitability classes and agricultural uses

Classes	Suitability classes	Rates	Potential agricul-tural uses
Class 1 (S_1)	Highly suitable	85-100	Excellent
Class 2 (S_2)	Moderately suitable	84-60	Good
Class 3 (S_3)	Marginally suitable	59-40	Fair
Class 4 (N_1)	Currently not suitable	39-20	Poor
Class 5 (N_2)	Permanently not suitable	< 20	Very poor

Adapted from Ezeaku (2011)

Table 2: Land/crop requirements for rainfed rice cultivation

Land qualities Factor ratings	Land characteristics	Unit	S_1 (100-85)	S_2 (84-60)	S_3 (59-40)	N_1 (39-20)	N_2 (19-0)
Climate (*c*)	Annual rainfall	mm	> 1400	1200-1400	950-1100	850-900	< 850
Soil physical characteristics (*s*)	Soil depth	cm	> 20	10-20	5-10	< 5	any
	Clay	%	45-25	25-15	15-5	< 5	any
	Texture	-	Loam	Clay loam	Clay	Sandy clay	any
Wetness (*w*)	Drainage	-	VPD	PD	MD	MWD	WD
	F.D.	months	> 4	3-4	2-3	< 2	any
	G.W.T.	cm	0-15	15-30	30-60	> 60	any
Fertility status (*f*)							
	pH (H_2O)	-	5.5-7.5	5.2-5.5	≤ 5.2, ≥ 8.2	≤ 5.2, ≥ 8.2	any
	Total nitrogen	g kg^{-1}	> 0.2	0.1-0.2	0.05- 0.1	< 0.05	any
	Organic carbon	g kg^{-1}	5-6	3-4	1-2	< 1	any
	Available P	mg kg^{-1}	> 20	15-20	10-15	< 10	any
	Exchangeable Ca	$cmol_c$ kg^{-1}	10-15	5-10	1-5	< 1, > 15	any
	Exchangeable Mg	$cmol_c kg^{-1}$	2-5	1-2	< 1	< 1, > 5	any
	Exchangeable K	$cmol_c kg^{-1}$	> 0.2	0.1-0.2	< 0.1	< 0.1	any
	CEC (soil)	$cmol_c$ kg^{-1}	> 16	10-16	5-10	< 5	any

S_1, S_2, S_3, N_1 and N_2 refer to highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable, respectively; F.D. - flooding duration, G.W.T. - ground water table, VPD - very poorly drained, PD - poorly drained, MD - moderately drained, MWD - moderately well drained, WD - well drained, CEC - cation exchange capacity, Ca - calcium, Mg - magnesium, K - potassium, Fe - iron. Adapted from Sys (1985) .

Table 3: Land/crop requirements for suitability classes for rainfed maize cultivation

Land qualities	S_1 (100-85)	S_2 (84-60)	S_3 (59-40)	N_1 (39-20)	N_2 (19-0)
Climate (*c*)					
Annual rainfall (mm)	1250-750	750-600	600-500	300-490	< 300
Length growing season (days)	150-270	270-325	325-345	any	> 345
Mean annual temperature (°C)	26-18	18-16	16-14	any	< 14
Relative humidity (%)	80-42	42-36	36-30	any	> 30
Topography (*t*)					
Slope (%)	0-4	4-8	8-16	any	> 16
Wetness (*w*)					
Drainage	Well	Moderate	Poor	Poor	Very poor
Soil physical properties (s)					
Texture	SC, L, SCL	SL, LFS, LS	C	any	S
Depth (cm)	> 100	75-100	50-75	20-50	< 20
Fertility (*f*)					
CEC ($cmol_c\ kg^{-1}$)	> 24	16-24	10-16	5-10	< 5
Base saturation (%)	> 50	35-50	20-35	< 20	any
Organic carbon (%)	> 2	1.2-2.0	0.8-1.2	< 0.8	any
pH-H_2O	5.5-7.5	5.0-5.5, 7.5-8.0	4.0-4.9, 8.0-8.5	4.0, 8.0	< 4.0, > 8.0
Total N (%)	> 0.15	0.10-0.15	0.08-0.10	0.04-0.08	< 0.04
Available P ($mg\ kg^{-1}$)	> 22	13-22	7-13	3-7	< 3
Exchangeable K ($cmol_c\ kg^{-1}$)	> 0.5	0.3-0.5	0.2-0.3	0.1-0.2	< 0.1
Exchangeable Ca ($cmol_c\ kg^{-1}$)	10-15	5-10	1-5	< 1, > 5	any
Exchangeable Mg ($cmol_c\ kg^{-1}$)	2-5	1-2	< 1	< 1, > 5	any

S_1, S_2, S_3, N_1 and N_2 refer to highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable, respectively; SC - sandy clay, L - loam, SCL - sandy clay loam, SL - sandy loam, LFS - loamy fine sand, LS - loamy sand, C - clay, S - sand, P - phosphorus, K - potassium, Ca - calcium, Mg - magnesium, N - nitrogen, CEC - cation exchange capacity. Modified from: Sys (1985)

RESULTS

General Characteristics of the Research Area

The soils of the research area were mainly derived from fluvial sand deposits (Plate 1) and sand stones. They occupy the lower physiographic regions of the eastern part of Kogi State with the elevation ranging from 74 to 164 m asl (Figure 4). The soils are moderately well drained to well-drained with slight erosion hazards. The mapping unit have deep soil profiles with depths greater than 150 cm.

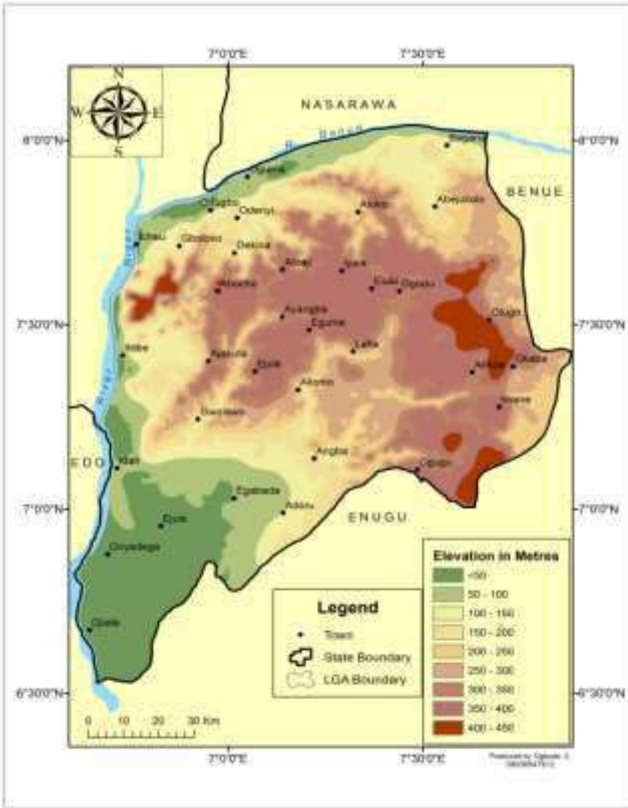

Figure 4: A topographic map of Kogi East

Morphological Characteristics of the Studied Soils

The morphological characteristics of the soils are presented in Table 4. The profiles were developed with colour (moist) variations of 10Y, 5Y, 2.5Y and 10R (Hue). Soil colours were 10YR4/1 (gray) and 10R4/1 (dark reddish gray) in the surface soils and dominance of various shades of gray in the subsurface soils. Soil texture predominantly ranged from sand, sandy loam to loam in both surface and subsurface soils with. However, silty clay was obtained in the subsurface soils of Ugwolawo ($19a_2$). Most of the soil structures were single-grained and subangular blocky as observed in $19a_2$ and $19a_3$ pedons. The consistence of the soils was predominantly non-sticky and non-plastic. Clear and wavy, were the dominant distinctness and topography of the boundaries between horizons observed. Few fine and faint light yellow (2.5Y7/8) mottle was observed at C2 soil horizon (soil depth: 152-180 cm) in the $19a_3$ pedon.

Physical characteristics of the Studied Soils

The physical characteristics of the soils are presented in Tables 5 and 6. The sand and clay distributions in the profiles are presented in Figure 5. The sand fraction of the soils had mean value of 716 g kg^{-1} in the surface and 780 g kg^{-1} in the subsurface soils. The mean value of silt and clay was 133 and 150 g kg^{-1} at the surface, 80 and 139 g kg^{-1} in the subsurface soils, respectively. The mean value of the silt/clay ratio was 0.10 and 0.63 in the surface and subsurface soils, respectively. Loamy sand and sandy loam textural classes respectively dominated the surface and subsurface soils. The mean values of the bulk density, total porosity and saturated hydraulic conductivity in the surface soils was 1.7 g cm^{-3}, 32.82% and 44.19 cm h^{-1} respectively, while respective mean value of 1.79 g cm^{-3}, 32.53% and 73.80 cm h^{-1} was observed in the subsurface soils.

Chemical Characteristics of the Soils

The chemical characteristics of the soils are presented in Table 7. The values of pH in H_2O were generally higher than pH in KCl, and varied between 5.9 and 6.2 in the surface when compared with 4.4 and 6.9 in the subsurface soils, respectively. The mean values of organic carbon (11.00 g kg^{-1}) and TN (0.85 g kg^{-1}) at the surface soils were higher when compared with the subsurface (3.30 and 0.57 g kg^{-1}, respectively).

The mean values of carbon: nitrogen and available phosphorus were 24 and 2.49 mg kg^{-1} in the surface while the subsurface soils had 7 and 3.26 mg kg^{-1} respectively. The exchangeable bases which irregularly decreased with depths had ranges of 1.00 to 10.6 $cmol_c$ kg^{-1}, 0.20 to 5.50 $cmol_c$ kg^{-1}, 0.08 to 0.14 $cmol_c$ kg^{-1} and 0.04 to 0.50 $cmol_c$ kg^{-1} at the surface soils; 0.60 to 6.60 $cmol_c$ kg^{-1}, 0.20 to 4.20 $cmol_c kg^{-1}$, 0.03 to 0.50 $cmol_c$ kg^{-1} and 0.02 to 0.05 $cmol_c$ kg^{-1} in the subsurface soils for the exchangeable Ca, Mg, K and Na, respectively. The effective cation exchange capacity (ECEC) which was influenced by the exchangeable hydrogen and aluminium was higher in the surface soils with a mean value of 8.07$cmol_c$ kg^{-1} than in the subsurface soils with a mean value of 6.39 $cmol_c$ kg^{-1}. Base saturation varied between 30 and 60% in the surface soils but ranged from 18 to 91% in the subsurface soils. Acid saturation at the surface soils varied between 6 and 30% while the range of 8-62% was obtained in the subsurface soils. The mean ESP values in the surface and subsurface soils were respectively 2.54 and 0.43%. The ASP was lower in surface than in the subsurface soils, having mean values of 6 and 16%, respectively.

Table 4: Soil morphological characteristics of the research area

Pedon/ Coordinate	Location	Horizon depth (cm)	Horizon desig- nation	Colour		Texture	Structure	Consistence		Boundary	Pores	Roots	Others¶
				Matrix	Mottles			Wet	Moist				
19a1	Itobe	0-15	Ap1	10Y4/1	-	scl	14g	nsnp	l	cw	cme	mmeco	-
07°24'29.7"N		15-32	Ap2	10YR5/2	-	sl	s	nsnp	l	gs	ffi	ffi	-
006°49'00.3"E		32-64	AB	5Y7/2	-	ls	s	nsnp	l	ds	ffi	fvfi	-
		64-101	BC1	5Y8/2	-	ls	s	nsnp	l	ds	ffi	fvfi	-
		101-160	BC2	7.5Y8/2	-	ls	s	nsnp	l	ds	ffi	fvfi	-
		160-219	BC3	7.5Y8/3		ls	s	nsnp	l	-			
19a2	Ugwolawo	0-29	Ap1	10R4/1	-	sil	14g	nsnp	l	cw	ffi	ffime	-
07°13' 26.2"N		29-72	Ap2	10R4/4	-	sl	15c	nsnp	vfr	cm	ffi	fme	-
006°54'39.3"E		72-120	AB	10R4/8	-	scl	24sbk	sssp	vfr	gs	ffi	ffi	-
		120-167	B1	2.5YR4/8	-	sic	25sbk	sssp	fr	ds	ffi	ffime	a
		167-202	B2	2.5YR5/8	-	sic	24sbk	sssp	fr	-	fvfi	fvfi	-
19a3	Ajegwu	0-24	Ap	7.5Y5/1	-	sl	145g	nsnp	l	gw	cme	fvfi	-
07°23'51.2"N		24-60	A	5YR5/4	-	cl	24c	nsnp	l	gs	fme	fvfi	-
006°47'11.0"E		60-110	BC	2.5Y6/4	-	ls	255c	nsnp	vfr	gs	cfi	cmeco	-
		110-152	C1	2.5Y8/3	-	s	s	nsnp	l	ds	ffi	cffi	-
		152-180	C2	2.5Y7/3	2.5Y7/8	s	s	nsnp	l	-	ffi	fvfi	-
19a4	Obakwume	0-15	Ap	2.5YR3/2	-	scl	25c	nsnp	vfr	gs	cfi	cfi	-
07°55'35.7"N		15-40	ABw	2.5YR4/4	-	scl	25sbk	sssp	vfr	ds	ffi	ffi	-
007°30'59.4"E		40-101	Bw1	2.5YR3/4	-	scl	25abk	sssp	fr	ds	fvfi	fvfi	b
		101-197	Bw2	7.5YR5/4	-	cl	26abk	sssp	fr	-	fvfi	fvfi	c

19a refers to soil mapping unit while $19a_1$ $19a_2$ $19a_3$ and $19a_4$ are the pedons in the unit.
Structure: 1 - weak, 2 - moderate, 3 - strong, 4 - fine, 5 - medium, 6 - coarse, c - crumb, g - granular, sbk - subangular, abk - angular blocky, s - single grain.
Texture: l - loam, s - sand, c - clay, si - silt, cl - clay loam, sl - sandy loam, scl - sandy clay loam, sc - sandy clay, g - gravelly, v - very, e - extremely, st - stony.
Consistency: sp - sticky and plastic, sssp - slightly sticky and slightly plastic, nsnp - non sticky and non-plastic, l - loose, vfr - very friable, fr - friable, f - firm, v - very firm. Pores and Roots: f - few, v - very, m - many, c - common, fi - fine, me - medium, co - coarse. Boundary: a - abrupt, c - clear, g - gradual, d - diffuse, s - smooth, w - wavy, i – irregular. ¶: [a]few ants, [b]few black ants, [c]few fine clay skins on ped faces

Table 5: Textural characteristics of soils of the research area

Pedon	Location	Depth (cm)	Horizon designation	C. sand	F. sand	Silt	Clay	Silt:Clay	Texture
				(g kg^{-1})					
19a1	Itobe	0-15	Ap1	570	210	130	90	1.44	sl
		15-32	Ap2	550	310	50	90	0.56	ls
		32-64	AB	610	270	30	90	0.33	ls
		64-101	BC1	550	310	50	90	0.56	ls
		101-160	BC2	540	340	30	90	0.33	ls
		160-219	BC3	540	340	30	90	0.33	ls
19a2	Ugwolawo	0-29	Ap1	430	410	70	90	0.76	ls
		29-72	Ap2	540	340	30	90	0.33	ls
		72-120	AB	350	490	50	110	0.45	ls
		120-167	B1	350	470	70	110	0.64	ls
		167-202	B2	420	400	50	130	0.38	sl
19a3	Ajegwu	0-24	Ap	700	160	70	70	1.00	ls
		24-60	A	600	220	110	70	1.57	ls
		60-110	BC	530	350	50	70	0.71	ls
		110-152	C1	620	280	30	70	0.43	s
		152-180	C2	510	290	130	70	1.86	ls
19a4	Obakwume	0-15	Ap	70	410	230	290	0.79	scl
		15-40	ABw	90	430	190	290	0.66	scl
		40-101	Bw1	50	470	170	310	0.55	scl
		101-197	Bw2	40	480	150	330	0.45	scl
Surface range				70-700	160-410	70-230	70-290	0.76-1.44	sl-ls-scl
Subsurface range				40-620	220-490	30-190	70-330	0.33-1.86	ls-s-scl
Surface mean				423	293	133	150	0.10	sl
Subsurface mean				419	361	80	139	0.63	ls

19a refers to soil mapping unit while $19a_1$ $19a_2$ $19a_3$ and $19a_4$ are the pedons in the unit.
C. sand - coarse sand, F. sand - fine sand; sl - sandy loam, ls - loamy sand, s - sand, scl - sandy clay loam

Table 6: Physical characteristics of the soils of the research area

Pedon	Location	Depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	K_{sat} (cm h^{-1})
$19a_1$	Itobe	0-25	1.87	29.43	40.48
		25-50	1.81	31.69	151.79
		50-75	1.72	35.09	101.19
$19a_2$	Ugwolawo	0-25	1.71	35.47	26.31
		25-50	1.87	29.43	62.74
		50-75	1.75	33.96	23.27
$19a_3$	Ajegwu	0-25	1.73	34.72	96.13
		25-50	1.77	33.21	109.58
		50-75	1.70	35.85	131.55
$19a_4$	Obakwume	0-25	1.79	32.45	3.04
		25-50	1.89	28.68	1.52
		50-75	1.78	32.83	3.04
Surface range			1.73-1.87	29.43-35.47	3.04-96.13
Subsurface range			1.70-1.89	28.68-35.85	1.52-151.79
Surface mean			1.78	32.82	44.19
Subsurface mean			1.79	32.53	73.80

19a refers to soil mapping unit while $19a_1$ $19a_2$ $19a_3$ and $19a_4$ are the pedons in the unit. K_{sat} - saturated hydraulic conductivity

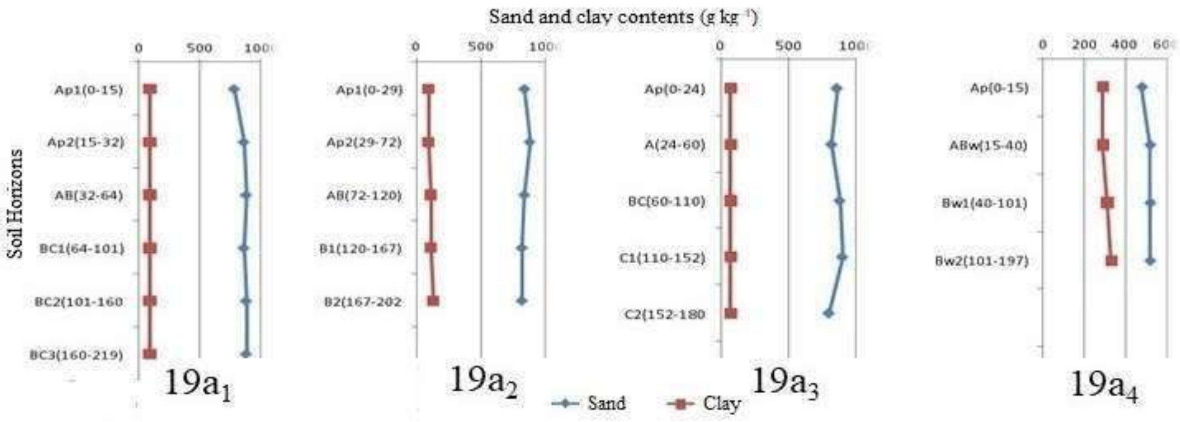

Figure 5: Profile sand and clay distribution in $19a_1$, $19a_2$, $19a_3$ and $19a_4$, respectively

Taxonomic Classification of the Studied Soils

The summary of taxonomic classifications of the pedons is presented in Table 8. The soils have ochric epipedon and cambic endopedon and so classified as *Inceptisols* at the order level. At Ajegwu ($19a_3$) pedon, redox concentration as shown by mottle colour of 2.5Y7/8 (faint yellow) was observed in the sub-surface layer (152-180 cm) (Table 4), indicating evidence of ground water fluctuations and qualifying it as *Aquepts* at the suborder level. The pedon is taken to the Great Group *Endoaquepts* due to the endo-saturation. According to the USDA Soil Taxonomy, this pedon is classified as *Dystric Endoaquepts* since the base saturation (by NH_4OAc) was less than 50% within 100 cm soil depth. The FAO-WRB equivalence of this pedon is *Dystric Fluvisol*s (*Arenic*), due to also less than 50% base saturation by 1 M NH_4OAc, pH 7, as well as having a texture class of loamy sand in layers less than 100 cm of the mineral soil surface. The $19a_1$, $19a_2$ and $19a_4$ were taken to the suborder, *Ustepts* since the soils occur within the environment with ustic soil moisture regime.

The Great Group classification of the pedons is *Dystrusteps* since there were no free carbonates within 200 cm of the mineral soil surface, and base saturation of less than 60 percent in most of the horizons at depths between 25 and 75 cm from the mineral soil surface. They were further classified as *Typic Dystrusteps* at the Subgroup level of the USDA Soil Taxonomy. The FAO-WRB equivalence is *Dystric Fluvisols* (*Arenic*) due to a dominant soil texture of loamy sand and sandy loam in most of the horizons less than 100 cm of the mineral soil surface.

Suitability Evaluation of Soils of the Research Area for Rainfed Rice and Maize Production

The suitability ratings and classifications of the soils for the cultivation of rice and maize under rainfed agriculture are presented in Tables 9-11. According to the qualitative method of land suitability evaluation by the FAO framework (1976), the results showed that the soils are not currently suitable for lowland rainfed rice cultivation. This is due to lack of adequate soil moisture to support cultivation of this crop as well as inadequate fertility. Under the parametric model of land suitability evaluation, the soils are currently not suitable (N_1) for rice cultivation. The result showed that qualitatively, the soils are currently only marginally suitable (S_3) for rainfed maize cultivation. Potentially, the studied soils are marginally suitable for rainfed maize cultivation due mainly to poor fertility limitations. Using the current productivity index of the parametric system of land evaluation (Ezeaku, 2011), the soils are marginally suitable (S_3) for rainfed maize cultivation. Potentially, they are also marginally suitable (S_3).

Table 7: Chemical characteristics of the soils of the research area

Pedon	Location	Depth (cm)	Horizon designation	pH		OC	TN	C:N	AvP	Exchangeable cations						EA	CEC	ECEC	TEB	PBS	ESP	ASP
				H_2O	KCl	(g kg^{-1})			(mg kg^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	(cmol$_c$ kg^{-1})				(%)		
$19a_1$	Itobe	0-15	Ap1	6.2	5.5	9.60	0.40	24	1.87	2.20	0.20	0.10	0.05	0.60	0.40	1.0	7.80	3.55	2.55	33	0.64	1
		15-32	Ap2	6.3	5.3	4.20	0.40	11	4.66	1.40	0.60	0.03	0.02	1.20	0.40	1.6	6.60	3.65	2.05	31	0.30	11
		32-64	AB	5.7	4.6	6.20	0.30	21	2.80	1.20	1.00	0.05	0.03	0.60	0.20	0.8	5.60	3.08	2.28	41	0.54	6
		64-101	BC1	5.7	4.6	1.30	0.30	4	1.87	3.40	0.80	0.09	0.05	-	0.40	0.4	5.40	4.74	4.34	80	0.93	8
		101-160	BC2	6.5	5.8	1.70	0.40	4	1.87	1.80	0.60	0.10	0.05	0.80	0.60	1.4	5.40	3.95	2.55	47	0.93	15
		160-219	BC3	6.9	5.9	1.70	0.90	2	1.87	1.00	0.20	0.10	0.05	-	0.60	0.6	5.40	1.95	1.35	25	0.93	31
$19a_2$	Ugwo-lawo	0-29	Ap1	5.9	5.1	9.00	1.50	6	1.87	1.40	1.00	0.10	0.50	-	0.40	0.4	7.40	3.40	3.00	41	6.76	12
		29-72	Ap2	5.5	4.0	4.50	0.40	11	7.46	1.00	0.40	0.50	0.03	1.40	0.40	1.8	7.00	3.73	1.93	28	0.43	11
		72-120	AB	5.3	4.1	2.90	0.60	5	4.66	0.80	0.40	0.03	0.02	1.60	0.20	1.8	7.00	3.05	1.25	18	0.29	7
		120-167	B1	4.9	4.0	2.10	0.70	3	3.73	0.80	0.40	0.03	0.02	2.00	-	2.0	7.00	3.25	1.25	18	0.29	-
		167-202	B2	4.9	4.0	3.30	0.60	6	3.73	0.80	0.60	0.03	0.02	1.20	-	1.2	7.40	2.65	1.45	20	0.27	-
$19a_3$	Ajegwu	0-24	Ap	6.2	5.3	1.10	0.90	1	3.73	1.00	1.20	0.08	0.04	1.00	-	1.0	7.80	3.32	2.32	30	0.51	-
		24-60	A	5.5	4.3	2.50	0.40	6	2.80	0.60	1.00	0.03	0.02	0.80	-	0.8	6.60	2.45	1.65	25	0.30	-
		60-110	BC	5.2	4.0	2.90	0.40	7	4.66	0.80	0.80	0.03	0.02	1.20	-	1.2	7.00	2.85	1.65	23	0.29	-
		110-152	C1	5.9	4.6	2.10	0.40	5	3.73	5.00	0.20	0.03	0.02	0.80	-	0.8	5.80	6.05	5.25	91	0.34	-
		152-180	C2	5.8	4.2	1.60	0.30	5	0.93	5.20	1.00	0.10	0.05	0.20	0.80	1.0	7.80	7.35	6.35	81	0.64	11
$19a_4$	Oba-kwume	0-15	Ap	5.9	4.9	22.60	0.40	56	1.87	10.60	5.60	0.14	0.08	0.60	0.40	1.0	27.20	17.42	16.42	60	0.29	2
		15-40	ABw	4.6	3.6	5.80	0.90	6	2.80	6.20	4.20	0.06	0.03	2.00	2.00	4.0	18.80	14.49	10.49	56	0.16	14
		40-101	Bw1	4.5	3.6	4.10	0.70	6	1.87	5.60	3.00	0.05	0.02	2.40	5.60	8.0	23.20	16.67	8.67	37	0.09	34
		101-197	Bw2	4.4	3.4	5.00	1.10	5	0.93	6.60	3.40	0.05	0.02	3.60	2.80	6.4	24.00	16.47	10.07	42	0.08	17
Surface range				5.9-6.2	4.9-5.5	1.10-22.60	0.40-1.50	1-56	1.87-3.73	1.00-10.6	0.20-5.60	0.08-0.14	0.04-0.50	0-1.00	0-0.40	0.4-1.0	7.40-27.2	3.32-17.42	2.32-16.42	30-60	0.29-6.76	1-12
Subsurface range				4.4-6.9	3.4-5.9	1.30-6.20	0.30-1.10	2-21	0.93-7.46	0.60-6.60	0.20-4.20	0.03-0.50	0.02-0.05	0.20-3.60	0.20-5.60	4-8	5.4-24.0	1.95-16.67	1.25-10.49	18-91	0.08-0.93	6-34
Surface mean				6.1	5.2	11.00	0.85	24	2.49	4.47	2.30	0.12	0.20	0.76	0.40	0.8	14.13	8.07	7.17	41	2.54	6
Subsurface mean				5.5	4.4	3.30	0.57	7	3.26	2.74	1.28	0.10	0.03	1.48	1.53	2.34	9.97	6.39	4.13	41	0.43	16

- is no significant value, OC - organic carbon, TN - total nitrogen, C:N - carbon-nitrogen ratio, AvP - available phosphorus, Ca^{2+} - exchangeable calcium, Mg^{2+} - exchangeable magnesium, K^+ - exchangeable potassium, Na^+ - exchangeable sodium, Al^{3+}- exchangeable aluminium, EA - exchangeable acidity, CEC - cation exchange capacity, ECEC - effective cation exchange capacity, TEB - total exchangeable bases, PBS - percentage base saturation, ESP - exchangeable sodium percentage, ASP - aluminium saturation percentage

Table 8: Classification of soils of the research area

Pedon	Location	USDA				FAO-WRB
		Order	Suborder	Great Group	Subgroup	
$19a_1$	Itobe	Inceptisols	Ustepts	Dystrusteps	Typic Dystrustepts	Dystric Fluvisols (Arenic)
$19a_2$	Ugwolawo	Inceptisols	Ustepts	Dystrusteps	Typic Dystrustepts	Dystric Fluvisols (Arenic)
$19a_3$	Ajegwu	Inceptisols	Aquepts	Endoaquepts	Dystric Endoaquepts	Dystric Fluvisols (Arenic)
$19a_4$	Obakwume	Inceptisols	Ustepts	Dystrusteps	Typic Dystrustepts	Dystric Fluvisols (Arenic)

Table 9: Suitability class scores of soils of the research area for rainfed rice cultivation

Land characteristics/units	Suitability class/score
Climate (*c*)	
Annual rainfall (mm)	S_2 (70)
Soil physical characteristics (*s*)	
Soil depth (cm)	S_1 (90)
Clay (%)	S_3 (40)
Texture	S_3 (50)
Wetness (*w*)	
Drainage	N_2 (10)
F.D. (months)	S_3 (40)
G.W.T. (cm)	N_2 (15)
Fertility status (*f*)	
pH-H_2O	S_3 (50)
Total nitrogen (g kg^{-1})	S_3 (50)
Organic carbon (g kg^{-1})	S_2 (70)
Available phosphorus (mg kg^{-1})	N_1 (30)
Exchangeable Ca ($cmol_c$ kg^{-1})	S_3 (50)
Exchangeable Mg ($cmol_c$ kg^{-1})	S_3 (50)
Exchangeable K ($cmol_c$ kg^{-1})	S_3 (50)
CEC ($cmol_c$ kg^{-1})	S_3 (50)

F.D. - flood duration, G.W.T. - ground water table, Ca - calcium, Mg - magnesium, K - potassium, CEC - cation exchange capacity, S_1 - highly suitable, S_2 - moderately suitable, S_3 - marginally suitable, N_1 - not currently suitable, N_2 - permanently not suitable

Table 10: Suitability class scores of soils of the research area for rainfed maize cultivation

Land qualities/units	Suitability class/score
Climate (*c*)	
Annual rainfall (mm)	S_1 (90)
Mean annual temperature (°C)	S_1 (95)
Relative humidity (%)	S_1 (80)
Topography (*t*)	
Slope (%)	S_2 (70)
Wetness (*w*)	
Drainage	S_1 (80)
Soil physical properties (*s*)	
Texture	S_2 (70)
Depth (cm)	S_1 (100)
Fertility (*f*)	
CEC ($cmol_c$ kg^{-1})	S_1 (80)
Base saturation (%)	S_2 (60)
Organic carbon (g kg^{-1})	S_2 (60)
pH-H_2O	S_3 (50)
Total nitrogen (g kg^{-1})	S_3 (50)
Available phosphorus (mg kg^{-1})	N_1 (30)
Exchangeable K ($cmol_c$ kg^{-1})	S_3 (40)
Exchangeable Ca ($cmol_c$ kg^{-1})	S_2 (60)
Exchangeable Mg ($cmol_c$ kg^{-1})	S_2 (60)

CEC - cation exchange capacity, K - potassium, Ca - calcium, Mg - magnesium, S_1 - highly suitable, S_2 - moderately suitable, S_3 - marginally suitable, N_1 - not currently suitable, N_2 - permanently not suitable

Table 11: Suitability classifications and aggregate scores of soils of the research area

	Rice	Maize
CC	N_1f	N_1f
CP	N_2w	S_3f
PC	N_1 (21)	S_3 (44)
PP	N_1 (22)	S_3 (54)

CC - conventional (current), CP - conventional (potential), PC - parametric (current), PP - parametric (potential), S_1 - highly suitable, S_2 - moderately suitable, S_3 - marginally suitable, N_1 - not currently suitable, N_2 - permanently not suitable, *f* - fertility, *w* - wetness

DISCUSSION

The soils of this unit are located in the lower slope areas, receiving fluvial deposits of higher percent coarse and fine sand, giving rise to dominant loamy sand and sandy loam soil textures. The various shades of gray colours represent poorly to moderately drained nature of the soils of this unit. Due to the low clay content, these soils are non-sticky and non-plastic with an exception in $19a_4$ soils. The low clay content of the soils of this unit resulted in higher bulk density and lower total porosity and high K_{sat} values. Sandy soils generally have higher K_{sat} values than clayey soils (Brady and Weil, 2002; Obalum *et al*., 2014). Invariably, the texture of the soils of this unit influenced the proportions of the chemical parameters of the soils. Soil texture influences many soil properties in far-reaching ways due to fundamental surface phenomena (Akamigbo, 1984; Brady and Weil, 2002). Water retention in these soils could be low due to little surface area. This problem is evident in the enhanced K_{sat}, suggesting dominance of macropores over micropores in the soils (Obalum *et al*., 2011) Also, dissolved chemicals do not have enough mineral particle surfaces for adsorption due to very low proportion of clay; hence, CEC and TEB are deficient in these soils except for $19a_4$ with a CEC range of 8.67-16.42 $cmol_c$ kg^{-1} and higher clay content with evidence of increase down the profile. Similar soils occurred in some inland depression soils of south-eastern Nigeria as documented by Akamigbo and Asadu (1986) and Effiong and Akpan (2013).

The mean values of silt-clay ratio in the surface and sub-surface soils of 0.10 and 0.63, respectively imply that, compared to the surface soils, the sub-surface soils have much more weatherable minerals (Obalum *et al*., 2012a). It is, therefore, possible to have the surface soils geologically fertilized with time.

The high sand content of the soils will not support moisture retention for the water-loving rice. Overall, they were adjudged not currently suitable for rainfed rice cultivation. Since the lowland *sawah*-rice can be superior over the traditional rainfed rice across soil textures, hydrological conditions and fertility gradients (Wakatsuki *et al.,* 2011a,b; Obalum *et al*., 2012b, 2014), rainfed *sawah* could be used to grow rice in these soils in the meantime. Adoption of this soil and water management system against pedological constraints in floodplains of the savanna zone has been proposed (Ukabiala *et al*., 2021). *Sawah* has many soil-related ecological and agronomic benefits (Igwe *et al*., 2011; Wakatsuki *et al.,* 2011b; Igwe and Wakatsuki, 2012). *Sawah* plots are bunded and puddled to control water and reduce soil macropore permeability, respectively (Obalum *et al*., 2012c, 2014; Igwe *et al.,* 2013), implying desired enhancement of water retention for the rice crop. Although this lowland rice-farming system typically involves irrigating the *sawah*-rice basins, locally irrigated *sawah*-rice systems may not even always out-yield their non-irrigated counterparts in humid tropical African environments (Issaka *et al*., 2009; Nwite *et al*., 2017; Nnadi *et al*., 2021).

Similarly, the soils being marginally suitable for maize cultivation with fertility limitations requires that manures and their combinations with inorganic fertilizers be used to improve their physical and chemical properties in maize production (Nwite *et al.,* 2012; Unagwu *et al.,* 2013; Uzoh *et al*., 2015; Ndzeshala *et al.,* 2022). This may ultimately place the soils at the class of moderate to high suitability for rainfed maize cultivation in the area.

CONCLUSION

This study aimed at the characterization, classification and suitability evaluation of soils formed in fluvial deposits within eastern part of Kogi State in Nigeria for rice and maize production. The soils are characterized by sandy clay to sandy clay loam to sand from the surface horizons to the subsurface. They were acidic with low soil organic carbon and cation exchange capacity. The base saturation was higher at the surface than at the subsurface. The soils were generally classified as *Inceptisols* at the order level of the USDA Soil Taxonomy. The soils were not currently suitable for optimum rainfed rice cultivation but were marginally suitable for maize cultivation with fertility limitations. If they must be used to grow rice under rainfed conditions, it is suggested that the farmer adopts the promising lowland *sawah* system of soil and water management in rice production. Also, efforts to improve on the fertility of the soils through management practices such as the incorporation of various forms of organic matter as well as inorganic fertilizers will improve their physical and chemical characteristics which may place them at the class of moderate to high suitability for rainfed maize cultivation.

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